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August 30th, 2007

Ms. Magalie Salas
Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, D.C. 20426

Re: Review of: Groves, P.A., J.A. Chandler, and R. Myers. 2007. White paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon; by Dale A. McCullough.

Dear Secretary Salas:

Please accept the attached peer review of the above referenced White Paper submitted by Idaho Power Company in July 2007. Please contact me at 208-843-7355 if there are any problems with the transmission of this filing.

Sincerely,

Ryan Sudbury
Staff Attorney

Review of: **Groves, P.A., J.A. Chandler, and R. Myers. 2007. White paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Final Report. Hells Canyon Complex, FERC No. 1971. July 2007.**

Dale A. McCullough
Columbia River Inter-Tribal Fish Commission
August 27, 2007

The recent review of the water temperature effects of Hells Canyon Complex on the Snake River fall Chinook by Groves, Chandler and Myers (2007) is evaluated here in each of its eight major parts. The work put into this IPC review was substantial and was thoughtfully done. Also, much new information was brought forward to this complex discussion that is useful in getting a fuller appreciation of the issues. Despite the depth of the response to each of the eight topic areas, it is my view that the IPC review does not present evidence on any of the topics that can argue successfully that providing warmer temperatures in the spawning season, allowing the thermal shift to persist, or that not addressing the summertime thermal problems below HCD is not a detriment to the Snake River fall Chinook. This is especially true given the substantial temperature increases that have already occurred in the Snake River in the last 50 years and the expected water temperature increases in the Snake River mainstem due to global climate change.

Also included is a brief discussion of Ehist. This was a computer temperature modeling effort conducted by IPC. In summary, much of the new information presented by IPC actually serves to further support the contention that IPC can make significant beneficial improvements to Snake River fall Chinook survival and production below HCD by effectively controlling water temperatures.

Adult Migration

3. The primary effect of this altered thermal regime to the various life stages are as follows:

a. *Adult migration* – There has been no apparent shift in adult migration timing. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above 20 °C between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.

This statement above concerning the current temperature exposure of Chinook appears to refer primarily to the temperatures experienced from the mouth of the Snake River through Lower Granite Reservoir. The basis for this statement is not given. There is no indication what is really implied by "similar." The comparison appears to be made between current temperatures from mid-August to mid-September vs. the temperatures in the mid-1950's (1955-1958). Elsewhere, IPC argues that temperatures in the mid-1950s are not suitable in establishing the baseline for the HCC because of the extensive development that had occurred in the Snake River plain. This argument also holds true for the lower Snake. Temperatures in the mid-1950's were undoubtedly significantly altered from historical values. In addition, a comparison with current Snake River temperatures is a comparison against the river modified by significant water releases from Dworshak Reservoir. Possibly Groves et al. (2007) are trying to establish that the addition of HCC to the Snake River didn't further alter the adult migration timing that was observed in the mid-1950s. However, water temperatures measured at Central Ferry (downstream of Lower Granite Dam, RM 83.2) in the mid-1950s with numerous pre-existing IPC dams other than the HCC, compared against current temperatures that represent effects of Dworshak releases, long-term global warming, and the addition of HCC is not a reassuring basis for claiming that temperature exposure and adult migration timing have not changed. If anything, it argues that the combination of climate change and HCC have negated the beneficial effects of the Dworshak releases, keeping the Snake River at the mid-1950s status as a thermally perturbed river.

Groves et al. (2007, p. 1)
Dam and as a result of the Hells Canyon Complex. Generally, upstream of the Hells Canyon Complex is warmer during the spring and summer months relative to the pre-development era (pre-1860). This thermal inertia influences the magnitude and duration of the thermal shift downstream of Hells Canyon Dam that was created by the operation of the HCC. This paper discusses what the effect of those changes are to fall Chinook

Is the "period of exposure" meant to imply that the accumulated time of exposure to temperatures >20°C is equal for the two different eras? It is likely that daily temperature fluctuation in the predevelopment period (free-flowing river) was greater than today with the reservoir system. Without some context, a statement such as this does not carry much meaning.

The Central Ferry water temperatures that were measured between 1955 and 1958 occurred before the HCC or lower Snake reservoirs were constructed. The use of Snake River water temperatures from the mid-1950s is not highly reflective of natural temperatures for the river given the high level of development that had already occurred in the Snake basin by this time. Also, there were 13 major hydropower dams on the Snake River above the HCC that preceded 1958. Of these dams, 11 of the 13 are owned by Idaho Power Company. (See notes for details). In addition, the current temperatures between mid-August and mid-September referred to are significantly influenced by coldwater releases from Dworshak Reservoir. So, a comparison of cooled lower Snake River temperatures against an elevated baseline thermal regime from the mid-1950s (which was noted as having greater maximum temperatures than the current regime is not a good basis on which to argue that there has been no apparent shift in adult migration timing. Both temperature regimes likely represent elevated thermal conditions and consequently, probably would both be linked to alterations in adult migration timing or at last altered thermal exposure during migration from pre-development.

Central Ferry water temperatures from 1957 and 1958 were very similar to those taken at Oxbow in the same years (USACE 1999, see figures in notes). If these temperatures are the same and the Central Ferry temperatures reach maxima of 25°C by mid-August (Groves et al.2007, p. 18), and the current temperatures upstream of HCC are warmer than pre-1860's temperatures (Groves et al. 2007, p. 1, p. 9), then it seems reasonable to conclude that temperatures throughout the entire Snake River mainstem in the 1950s were higher than before significant development.

p. 39 Groves et al. (2007) state:

> If migrating adult fall Chinook salmon were to remain in the vicinity of Ice Harbor Dam (close to the mouth of the Snake River), it is conceivable that they could be exposed to temperatures ≥19.0°C for about 46 days (with a maximum mean temperature of about 22.0°C). However, as has been discussed earlier, migrating adult salmon have been observed to quickly move through these areas (Peery et al. 2003). Similarly, if adult fall Chinook salmon remained in the vicinity of Lower Granite Dam, it is conceivable that they could be exposed to temperatures of approximately 19°C for about 28 days (with a maximum mean temperature of about 18.5°C). It generally takes adult salmon only a couple of days to navigate through the Lower Granite Reservoir and into the vicinity of the lower Clearwater River and the lower Hells Canyon Reach of the Snake River. It may

There have been numerous references to migration blockages that have occurred at temperatures of approximately 21-23°C (McCullough et al. 2001). This tends to be exacerbated when dissolved oxygen concentrations are low. Other studies have shown that impoundments can facilitate upstream passage rate by reducing flow velocities. However, temperatures >20°C are also responsible for significantly reduced rates of adult travel to spawning grounds (Goniea et al. 2006, see notes). In addition, maximum swimming speed in PIT-tagged Chinook was observed at 16.3°C (Salinger and Anderson 2006, see notes). Slowed migration is associated with cumulative effects of the hydrosystem and impairs migration success (Naughton et al. 2005, see notes).

<u>Pre-spawn mortality</u>

b. *Pre-spawn mortality* – Some level of pre-spawning mortality among anadromous salmonids is common. There is evidence that adult salmon in hatchery holding environments exposed to prolonged periods of water temperatures > 19 °C could be subject to significant pre-spawn mortality. In hatchery holding situations, the mortality is usually associated with increased susceptibility to disease. However, fish-to-redd ratios documented in the Snake River do not suggest excessive pre-spawn mortality of fall Chinook salmon. It may be that the non-confined environment of a large river under a naturally declining thermal regime and the availability of cooler refuge makes fish less susceptible to disease and mortality. In addition, the HCC has cooled late summer outflows relative to levels associated with the inflow temperature and the operations of Dworshak Reservoir substantially cool areas associated with Lower Granite Reservoir and create thermal refugia during the early pre-spawn environment such that conditions prevalent today are better than conditions prior to the HCC.

IPC acknowledges that holding temperatures >19°C have been noted as causing excess mortalities. This contention is supported by Berman and Quinn (1989).

IPC implies that the Snake River below HCD is not subject to this impact because (1) temperatures there are not excessive or not "prolonged," and (2) diseases that often accompany or are linked to thermal death are more associated with hatchery situations. Temperatures below HCD during the holding period (approx. September to December) have temperatures >19°C (and >20°C as the ODEQ temperature standard) during September and to mid-October. While disease incidence is more common in hatchery environments than in the wild, diseases are certainly known from stream environments and are thought to be much more common than typically assumed (Hershberger 2002, cited in Ruggerone 2004).

A large river has a lower contagion factor due to lower density of fish than would be typical of hatchery environments. However, passage through dams concentrates fish in fish ladders where salmonids come into contact with many fish species and diseases. This has long been considered to be a key mechanism for disease propagation. Warmwater disease incidence and proliferation increase significantly at temperatures above 15°C. Concentration of fish into thermal refugia in a warmed river also increases risk of disease spread. In addition, historic fall Chinook population densities were far greater than those of today so population density needs to be higher in the future and less susceptible to warmwater disease. Dam operations should not be in the position of claiming credits for maintaining low population densities in the interest of reducing disease transmission. It is more appropriate to maintain temperatures within standards and near historic values and timing to ensure low disease levels.

Groves et al. (2007) state:

p. 39

Within the Snake River, adult fall Chinook salmon can pass into and hold within several different river reaches, all having different thermal characteristics. As well, if adult fish within the Snake River are experiencing less than optimal water temperature, they have the ability to freely move among the various reaches and seek out thermal refuges. Fish

p. 39

cooler temperatures (generally a maximum of approximately 15°C). Near the confluence of the Snake and Clearwater rivers, there is a significant cool water refuge available for upstream migrating adult fall Chinook salmon, largely because of the cooling effect of releasing water from Dworshak Reservoir. The *earliest* fish entering the lower Hells Canyon Reach of the Snake River could conceivably experience water temperatures ≥19.0°C for about 32 days (with a maximum mean temperature of about 22.0°C). Again,

> if these fish experience thermal stress, they could move back downstream into a more amenable thermal refuge near or in the Clearwater River, or could even continue moving upstream into areas where other thermal refuges exist. For example, water entering the Snake River from the Grande Ronde River (Snake RM 168) tends to be <19.0°C by 1 September, and is cooling rapidly. There are also similar cool water refuges further upriver near the mouths of the Salmon and Imnaha rivers, and at many other smaller tributaries throughout the upper Hells Canyon Reach (such as Divide Creek, Zig-Zag

However, Connor et al. (2005, see notes) and Clabough and Stuehrenberg (2006, see notes) state that thermal refugia are limiting in the contemporary fall Chinook spawning areas. Berman and Quinn (1991, see notes) state that the availability of thermal refuges can affect population productivity. Also, even if cooler refuges exist in certain points in the Snake system, the need to hold there until late in the season prior to spawning and then to migration upstream to re-establish spawning sites upstream may tax the ability of the fish to adapt to the spatial limitation in refuge availability.

From the compilation of small tributaries cited by Groves et al. (2007) it is unclear that the fall discharge provided by these tributaries would be significant enough in volume and cold water to provide a thermal refuge and whether if these flow entry points that might exist are sufficiently shielded from mixing with the mainstem flow that they create a significantly large refuge. It is likely that these represent only potential points of refuge assuming flows are not diverted or that water temperature are not heated from land use practices. I believe that it is the intent of EPA that the mainstem would achieve summer temperatures ≤ 20°C but in the process of specifying this general temperature limit, there should be refugia that are well-distributed to provide temperatures that are more nearly optimum for salmon holding. IPC should not be counting on fall Chinook to hold for prolonged periods in the Clearwater, only to dash up to the HCD to spawn (see Keefer et al. 2004, in notes). It also cannot promote temperatures >20°C and then rely on thermal refugia that may or may not be present to compensate for the lack of temperature regulation.

The 7-DADM temperature of 13°C for spawning as adopted by Oregon and Idaho is based on the 7 days following October 23 (the assigned average first day of spawning). This running average of the daily maximum temperature is based on October 23-29. This means that the temperature on October 23 might be, for example, 14.0°C and on October 29 it might be 12.5°C. If the average daily maximum for this 7-day period is ≤ 13°C, it would meet the standard. This system of temperature accounting permits IPC to keep temperatures higher for longer in the fall than seems justifiable. That is, spawning between October 23 and October 26 is apt to be at a temperature >13.0°C. Achieving a temperature of 13°C on October 23 ±3 days (i.e., an average of October 20-26) would seem more appropriate.

Groves et al. (2007, p. 56)

treatment. These eggs had a final mortality of 13%, and had been initially exposed to a water temperature of 15.6° C for 5 days. Unfortunately, as with all other studies, no replicates were maintained within any temperature treatment. Therefore, there was no possibility to test for statistical differences due to treatments. However, the data from the spawning of 24 September strongly suggest that final mortality is not so much due to the actual thermal exposure, but more to the length of time that embryos are exposed to an elevated water temperature (Figure 11).

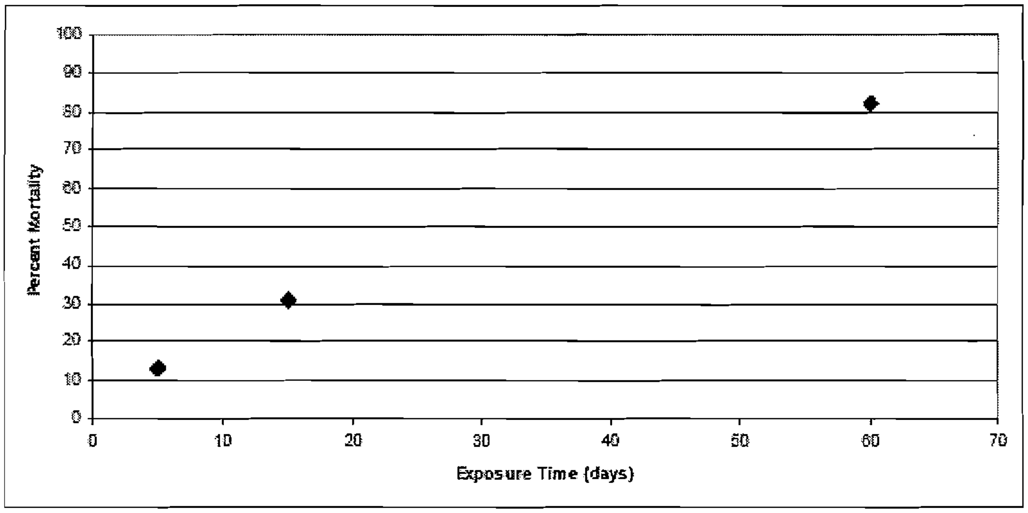

Figure 11. Percent mortality of Chinook salmon embryos dependant on exposure time (days) to water temperature of approximately 15.6 degrees C (data from Healey 1979).

Groves et al. make two points in the material above from p. 56 concerning the Healey (1979) paper. On this paper and on many others they lay the criticism that there are no replicates for temperature-exposure combinations. It is definitely desirable to have replicates but it is far from a fatal flaw in these studies not to have them. For example, if a study examined the response to 3 constant temperatures, 10, 13, and 17°C, with replication and it showed that at 17°C there was 100% mortality but at 13°C mortality was 5%, is this better than a study that showed the response to 10, 12, 14, 15, 16, and 17°C without replication? In the second study it might be revealed that there was 5%, 15%, and 30% mortality at 12, 14, and 15°C, respectively. This study provides more information than does the one with replication.

Groves et al. (2007) are correct in pointing out that thermal effects are a function of both temperature and exposure time. This is not new information, however. It is the basis for all incipient lethal temperature studies that have been done. However, temperature effects during incubation have generally been studied using constant temperatures. Groves et al. point out the effects of exposure times using the Healey (1979) data at 15.6°C. According to their graph, percentage mortality increases from approximately 12% at 5-days exposure to 31% at 15-days exposure, and 83% mortality at 60-days exposure at 15.6°C. If the constant incubation temperature were raised to 16.5°C, one would expect higher percentage mortalities at all exposure times. Groves et al. might argue that mortalities in a 1-day exposure as opposed to 5-day are minimal and of no consequence to the listed population. However, above the optimal incubation temperature of 13°C set by EPA, incremental increases in mortality were anticipated. IPC counts on only a 0.2°C reduction per day which for all intensts is a relatively constant temperature over the initial 5 days. It is for this reason that an incubation temperature toward the high end of optimal was selected as a threshold. EPA recognized that temperatures decline during the initial incubation period, are relatively stable during the middle incubation period, and rise in spring for the Pacific salmon. It would not be acceptable to maintain a temperature of 13°C during winter, even though it is identified as within the optimum range, because of the implications in emergence timing, which are dependent upon acquiring needed thermal units to emigrate at ecologically opportune times. Also, excess mortalities are avoided by application of an initial spawning temperature of 13°C (upper end of optimum). If temperatures were as benign as implied by IPC between 13 and 16.5°C, earlier spawning at these temperatures could occur prior to October 23.

Groves et al. (2007, p. 20).
survival of adult Chinook salmon prior to spawning. All of the pertinent literature available pertaining to Chinook salmon pre-spawn mortality in relation to water temperature is based on studies of spring or summer Chinook salmon (Coutant 1970, Becker 1973, Lindsay et al. 1989, Berman 1990, Jensen et al. 2005, Jensen et al. 2006). The actual cause of death in most all cases is outbreak of disease associated with long exposure times (as much as seven weeks) at elevated water temperatures (≥19.0°C) and fish being held in stressful conditions and in close contact with each other (e.g. hatchery holding ponds).

The statement above by Groves et al. (2007) overlooks much available literature on pre-spawning mortality of fall chinook. Much pre-spawn mortality data are available from California rivers and is cited by State of California (2004, see notes) for the Lower Feather River and other California rivers. Although hatchery conditions can exacerbate disease effects, it is inaccurate to imply that pre-spawning mortality is a problem only where fish are being held under hatchery conditions.

Brown and Geist (2002) studied the energy expenditure of Klickitat River fall chinook. They found that the extreme energy demands on these fish combined with delays in spawning could result in inability to spawn. Given the far greater energy demands on Snake River fall Chinook spawners, it is likely that bioenergetic concerns on spawning ability would be greater. This argues for moderated pre-spawning and migration temperatures to improve the spawning success.

Gamete Viability

c. *Gamete viability* – A through review of the literature demonstrates that studies often cited to suggest reduced gamete viability as a result of prolonged exposure to warmer temperatures should not be cited as supporting literature. The studies typically were not designed to address the question. One study that could be cited as supporting evidence (Jensen et al. 2006) did not hold adult Chinook salmon in a declining thermal regime typical of a riverine environment, but rather exemplified relatively long-term (40-days) exposure to elevated water temperatures. In addition, the control group held fish in a constant thermal environment of between 8 and 9 °C, which cannot be compared to a declining thermal regime under more normative environments. Based on the available information, it is difficult to conclude that the HCC has had an adverse effect on development of gametes in returning adult fall Chinook salmon.

The comment that any study is invalid that does not utilize a declining thermal regime to examine the effect of temperature on gamete viability is itself invalid. Holding by fall Chinook prior to spawning occurs during September and October and into December in the Snake River. Temperatures do not significantly decline from summer to October 1 below HCD. From July 9 to September 27, 1998, there was an 80-day period in which the temperature of the Snake below HCD varies from 20 to 23°C. Between September 1 and October 10, temperatures vary from approximately 22 to 18°C. The value of the Jensen et al. (2004) study on pink salmon is to show that temperature exposure for a lengthy period prior to spawning can negatively influence gamete viability.

Groves et al. (2007) did not cite the study by Mann and Peery (2004, see notes) that showed that Chinook exposed to temperatures as high as 23.6°C during migration had a high incidence of embryo mortality. Other reports cite a large body of literature indicating impact of rearing temperature on gamete viability (e.g., Berejikian 2005, see notes; also see references of Berejikian).

Disease Susceptibility

d. *Disease susceptibility* – Similar to the findings discussed under pre-spawn mortality, adults held in confined hatchery environments under prolonged periods of elevated temperature appear to have a greater susceptibility to disease or fungal infections. How this pertains to free-ranging adults is uncertain. However as discussed above, fish-to-redd ratios do not suggest a high level of pre-spawn mortality below Hells Canyon Dam.

It is probably true that disease problems under hatchery conditions are more severe and frequent than for wild populations. However, it is still valid to use known relationships between temperature under hatchery and natural field conditions relative to disease outbreaks to establish precautionary thresholds to be applied to natural populations. There is always uncertainty concerning application of any instance of a relationship between water quality conditions and biotic response to other instances of similar water quality conditions, whether it be in hatchery or natural environments. However, the number of cases documenting the significance of high temperatures in relation to outbreaks of warmwater diseases in salmonids necessitates assuming that nuances such as differences in populations among a single species and differences in precise temperature fluctuation patterns (e.g., constant, increasing, declining) during exposure are subservient to the overriding issue of exposure to high temperatures, especially when the level of temperature variation is not large.

Groves et al. (2007) pointed to the Snake River temperature history at Central Ferry below the site of Lower Granite Dam as a useful record for the period 1955-1958. Central Ferry water temperatures for 1958 reached at least 24°C and probably 26°C in 1958 (USACE figures, see notes). In addition, Richards (1959 and 1960, see notes) reported a high incidence (77.0%) of columnaris in Snake River fall Chinook in 1958 and in 1959 (or 1960) (62.2%).

Fish-to-redd ratios were cited numerous times as a key piece of evidence that pre-spawning mortalities were low below HCD. The premise of this statement is that if there is a difference between the ratios of fish counts at Lower Granite Dam and redd counts in the Snake River mainstem and tributaries among years, then one might infer that this is attributable to variation in prespawning mortality. Numbers of adults counted passing the dam and numbers of redds both are related to the total escapement. Adult counts should be corrected for fallback and the number of females would be most highly related to the number of redds. There are a number of reasons why this is not a strong piece of information for use in claiming no variation in pre-spawning mortality:

(1) The calculation of fish counts at the dams has a significant level of uncertainty due to a variety of factors, such as observer error and variation in detection rate (e.g., see Brown and Newton 2001, see notes).
(2) There is a variable level of fallback, which can be related to flows and temperature.
(3) Fish counts may include jacks, which can assume variable importance in spawning, depending upon the availability of older males in the population. The percentage of jacks in the spawning run has varied from as much as from 15 to 50% of the run, based on the 1955 to 1958 data from IDFG for fall Chinook passage above Oxbow Dam. The number of redds would depend significantly on the percentage of jacks.
(4) There is annual variation in male/female ratio among years (Howell et al. 1985, see notes).
(5) A female can dig more than one redd. It is uncertain to what extent the number of redds per female is constant from year to year.
(6) It assumes that the percentage of females in escapement that will spawn is the same from year to year.
(7) In some years the ability to detect redds is low relative to other years due to turbidity. There could be a greater concentration of spawning in some years in deep water vs. shallow water. Factors such as this can broaden the fish-to-redd

ratios observed from year to year, but can also create enough variation in the ratio so that variation due to pre-spawning mortality cannot be effectively detected.

(8) *When all of these data are compiled and analyzed relative to the total number of adult fall Chinook salmon allowed to pass upstream of Lower Granite Dam (with fallback and over-counting at the dam taken into account), the resulting fish to redd ratio has averaged 3.2 (range 2.0-4.2, data from 1993-2006). This comports well with (or better than) estimates of fish to redd ratios for the Hanford Reach of the Columbia River (3.0-16.0), where pre-spawn mortality is not considered to be a problem (Visser et al. 2002), and has never been reported as "excessive". (Groves, Chandler, and Myers 2007).* If the fish-to-redd ratio averages 3.2 and is 3.2 one year, but is 4.2 the next year, it is possible that pre-spawning mortality could be 0% the first year and 23.8% the next year due to temperature conditions. This is calculated as 420 fish pass the dam but 100 die (i.e., 23.8%), and the remaining 320 produce 100 redds (fish-to-redd ratio observed is 4.2). However, if 320 fish pass the dam with no mortality and produce 100 redds, the fish-to-redd ratio is 3.2. This level of pre-spawning mortality could cause this degree of variation in fish-to-redd ratio. This level of variation could also be entirely due to variation in counts of either fish passage or redds or both. If 10% of the fish passing the dam are not counted, they could all be mortalities due to temperature conditions, yet the ratio could remain unchanged. If there is a 10% error in identification of males and females such that there are really 10% more males than reported one year vs. the next, the fish-to-redd ratio would be higher than expected for no apparent reason.

Spawn Timing

e. *Spawn timing* – There is no evidence that spawn timing has been greatly altered in the Snake River when comparing pre-HCC spawn distribution to that of the present-day Hells Canyon spawn distribution.

Evidence for the pre-HCC spawn distribution comes from the IDFG spawning reports from 1958-1960 (Richards, IDFG, see notes). These reports show that about 1% of the fall Chinook run passed Oxbow Dam site in August, but that 67% were transported past Oxbow in September. Passage in September accounted for 23.5% of the total run in 1957 and 51% of the run in 1959. Spawning ground counts were made on November 10 and 11. Consequently, there is no real indication when spawning actually took place. It could be that the counts were made on November 10 and 11 to ensure being able to detect the full spawning run in a single pass. These data then do not indicate the distribution of spawning, but they do indicate the dates of passage at Oxbow Dam.

Groves et al. (2007, p. 40) also state the following relative to spawn timing:

With respect to delay of the actual spawning activity, there is evidence that a shift toward earlier spawning might be feasible if the river corridor could be cooled substantially. However, it would likely be very difficult to cool the river enough to make a reasonable shift in spawn timing. Data from 16 years of spawning surveys in the Snake River indicates that initial spawning is not consistently initiated because of either photo period or water temperature (Table 3). In the upper Hells Canyon Reach, the earliest spawning

In addition, they state (p. 43):

> Further, spawn timing appears to be strongly associated with a declining thermal regime and likely other environmental cues that are consistent regardless of water temperature, such as photoperiod, rather than a specific water temperature.

Spawning may be associated with a declining temperature regime, but Groves et al. (2007) do not present any evidence that this is more significant than initial spawning temperature. Tables presented by these authors indicate that temperature is highly significant in initiating spawning. Table 3 (p. 41) shows that over the period 1991-2006, in 13 of the 16 years, spawning in the upper Hells Canyon Reach commenced at 7-day mean water temperatures of <16.6°C and after October 18. By averaging day number for these 13 years, one can calculate a mean date of first spawning of approximately October 26. Using the entire 16-year data set, the mean date of first spawning was October 23. There were only 2 instances of early (prior to October 18) spawning at higher temperatures (October 9 at 17.3 and 19.1°C). No evidence was provided that temperatures on October 9 were declining to produce spawning. It is not uncommon for Chinook spawning to be noted at 19°C (see McCullough 2006 compilation of literature; also State of California 2004, see notes), but this is no indication that survival would be high. If the Geist et al. (2006) study results are used, one would infer very high mortality at these initial temperatures. Initial spawning as late as November 11 may indicate delayed spawning due to a variety of reasons. It would be an adaptive advantage to delay spawning until temperatures decline to favorable survival temperatures. If it takes a lengthy period for temperatures to decline sufficiently, it is also adaptive for the fish to spawn at the earliest opportunity to provide the greatest chance of emerging as early as possible. This would represent a tradeoff between spawning temperature and date. In the lower Hells Canyon Reach of the Snake River, in 15 of the 16 years, the mean water temperature during the 7 days prior to first observed spawning was 13.5°C. Only in 2001 did first spawning occur at high temperatures in the lower HC Reach (i.e., at 17.9°C). In 2001, first spawning occurred on October 9 in both the lower and upper HC Reaches at high temperatures. An explanation for this is uncertain. Possibly passage difficulties depleted the Chinook energetically, creating an immediate need for spawning prior to death. In any case, photoperiod is not a likely reason for variation in spawning times because the latitudes involved in the Snake River are not significantly different.

In the Clearwater River (see Groves et al., Table 4, p. 42), the mean water temperature at Lewiston for the 7-day period prior to first spawning was 13.1°C for four years having temperature data. The spawning initiation occurred between September 23 and October 1 in these years. Temperatures in the Clearwater River measured at Peck were approximately 2°C colder than at Lewiston. It is difficult, without more information, to know where the fall Chinook were holding prior to spawning and which temperature data set (i.e., either Lewiston or Peck) applies better to the environment in the holding area and spawning area. Despite this issue, it appears that spawning in the Clearwater River is initiated more frequently at earlier dates than in the Hells Canyon Reach and at temperatures <13°C. For all years for which first spawning dates were indicated, a conversion to day number, averaging day numbers, and converting back to date reveals that first spawning in the Clearwater was approximately October 3 on average.

First spawning of fall Chinook in the Grande Ronde River occurred at an average water temperature of 10.6°C for the 10 years of data between 1992 and 2006 having water temperature data available (Groves et al. 2007, p. 42). Water temperature data were based on the 7 days prior to spawning (whereas the Oregon and Idaho rules use the trailing 7-day period). First spawning dates in the Grande Ronde ranged from October 9 to October 26 for the years having water temperature data. Fall Chinook apparently are not choosing the option of spawning earlier at temperatures >13°C in either the Clearwater or the Grande Ronde. In the Clearwater, spawning at an average date of October 3 provides fall Chinook the advantage of advanced emergence and more lengthy rearing opportunity to achieve a large size prior to either emigration or overwintering, depending upon the life history alternative utilized (age-0 or age-1). In the Grande Ronde, the fact that fall Chinook spawn in mid-October at optimum initial temperatures (i.e., <13°C) may indicate that these fish are able to emerge at times appropriate to enable emigration in a timely manner at this point in the river and still spawn as late as they do. Without knowing the rate of river warming in the spring or the thermal accumulation during the incubation period in the Grande Ronde relative to that in the Snake River below HCD, it is difficult to compare the tradeoffs involved in initial spawning dates vs. initial temperature.

In summary, from information provided by Groves et al. (2007) it appears there is further support to the idea that temperatures <13°C are preferred as initial spawning temperatures. Also, it appears that spawning date can be advanced as much as 20 days by lowering temperatures from 15.1°C (average initial temperature for spawning in 13 of 16 years in upper Hells Canyon Reach) to 13.1°C in the Clearwater. Another way to view this is that the thermal shift has been approximately 3 weeks below HCD. If we achieve threshold spawning temperature standards three weeks earlier or if we restore the thermal regime by removing the thermal shift, spawning would be able to commence up to 3 weeks earlier.

Groves et al. (2007, p. 14).

As discussed later (section 4.5), there is little evidence that spawn timing has changed appreciably today as compared to spawn timing prior to the construction of the Hells Canyon Complex below Swan Falls Dam. Spawning was initiated in early October and extended over a relatively prolonged period through early December, with peak spawning occurring around the first week of November (Zimmer 1950). This is very similar to what has been observed today in the spawning area below Hells Canyon Dam. This

It is stated on p. 14 of the white paper that there is little evidence of a change in spawn timing. Zimmer (1950, see notes) noted that spawning started in late September. This is different from the October 23 date established for the IPC below HCD. Groves et al. (2007) stated that peak spawning occurred in the first week of November. Counts in 1949 by Zimmer (1950) revealed a nearly equal number of redds on October 18 as on November 22 from aerial surveys in the Swan Falls to Murphy Bridge reach. Redds counted on the first survey date were not included in the later count. This would indicate that all redd construction in the weeks prior to October 18 were equal to the redds constructed after October 18. This doesn't appear to indicate that early November is a peak in spawning. In 1947 there appears to be better evidence of a spawning peak in early November. However, 26% of the redds deposited between Swan Falls and Weiser surveyed by plane were deposited prior to October 17. Again, this indicates considerable spawning at an earlier date than the October 23 date set for IPC below HCD. The actual date of first spawning is given as late September. The magnitude of spawning this early is difficult to infer from the tables of redds by date for 1947 because the counts made prior to October 17 were made by ground or boat observation, which was noted as being extremely unreliable compared with the plane. In 1949 the first survey date was October 18 and half the total counts were observed by this date, which would indicate that substantial spawning occurs prior to October 18. By contrast, the earliest observed spawning between 1991 and 2006 cited by Groves et al. (2007, p. 41) was October 9 in 2000 and 2001. The mean date of first spawning for this 16-year period was October 23 below HCD. This appears to indicate that first spawning in the reach from Swan Falls to Weiser started approximately 4 weeks earlier based on data from Zimmer (1950).

Incubation Survival

f. *Incubation Survival* – Experiments based on constant and declining thermal regimes differ markedly in their results with respect to both ultimate survival and size of fry at emergence. To assess the thermal requirements of incubating eggs in a natural declining thermal regime, Olson and Foster (1955), Olson et al. (1970) and Geist et al. (2006) are the most applicable findings to conditions experienced by Snake River fall Chinook salmon. These studies suggest that eggs spawned at initial temperatures of between 16 °C to16.5 °C do not experience different levels of mortality from those eggs spawned at temperatures as low as 13 °C. At temperatures above 16.5 °C, mortality of incubating embryos substantially increases. The thermal shift that occurs below Hells Canyon Dam delays cooling of water temperature in the fall and significantly advances the emergence timing of juvenile fall Chinook salmon closer to what occurred historically in the primary production areas upstream of the Hells Canyon Complex. The HCC is now more suitable for the expression of an Age-0 fall Chinook salmon life history than it was before construction of the HCC. The elevated winter base temperatures also contribute to the advanced emergence timing relative to pre-HCC.

Groves, Chandler, and Myers (2007) dealt with the Olson et al. (1970) data that provide evidence of negative effects of declining temperature regimes with lower initial temperatures than reflected in Geist et al. (2006) by merging data from Olson and Foster (1955), Olson et al. (1970), and Geist et al. (2006). Although Groves et al. (2007) emphasize the importance of having statistics of variance based on replication with which to test the differences in biological response to temperature, their method serves only to create ambiguity by artificially expanding the range in response and making differences non-significant at an $\alpha = 0.05$ level (a significance level that places the burden on the fish and is not precautionary). Merging data from different studies is not a valid means of creating replicates. This amalgamation process indicated that a temperature of approximately >16.0°C is needed in a declining temperature regime to produce significantly greater fry mortalities. Although statistical tests are often desirable, it is not appropriate to obliterate results that differ from one test by averaging it with results from other studies. The Olson et al. (1970) study itself states that it discounts its results from its November 30 test initiation date due to highly variable outcome.

The October 30 test initiation date of Olson et al. (1970) is the one most similar to spawn timing occurring below HCD. It is reasonable to interpret these results as producing a significant increase in mortality between initial temperatures of 56.6 and 58.6°F. Groves et al. (2007) are correct that there was a single day upward tick in temperatures by approximately 0.6°F that could be interpreted as creating initial temperatures that were actually about 57.2 (14.0°C) and 59.2°F (15.1°C).

In the November 14 test, mortality increased approximately 50% over the temperature range from 13.9 to 16.2°C. Mortality then more than tripled as initial test temperature increased to 17.3°C.

Olson et al. (1970) discarded the November 23 test data. It is not clear whether Groves et al. (2007) averaged in these values with the other data or not.

The Olson et al. (1970) data for a December 8 initial test exposure indicated that in the comparison of egg lots at initial temperatures of 12.3 and 13.4°C, percentage mortality (eggs plus fish) doubled with this increase in initial temperature and remained doubled as initial temperatures increased to their maximum level of 15.0°C.

Groves et al. (2007) state that the HCC is now more suitable for expression of age-0 fall Chinook life history than before construction of the HCC. This is based on the contention that:

(1) The combination of spawning time and temperatures up to 16.5°C are ideal initial spawning and incubation temperatures; spawning that occurs before October 23 at higher temperatures constitutes a small percentage of the population and can be ignored; achieving a temperature of ≤ 16.5°C by October 23 is adequate for timing of spawning initiation and temperature regime; there has been no delay in spawning initiation from either the 1950s or prior to significant development of the Snake River system (i.e., prior to 1900),

(2) Any temperatures exceeding standards can be excused by either high air temperature exemptions or low flow exemptions,

(3) Biological consequences of further climate change predicted for the Snake River for the next 50 years by the majority of professional climatologists can be either ignored or can be excused by an exemption. Unfortunately, climate change and river temperature increases that have been documented over the past 50 years have caused fall Chinook and other salmonids to exist closer to thermal tolerance limits and to shift their spawn and emergence timing to compensate.

(4) The thermal shift that occurs in the fall is beneficial because it results in prolonged warm temperatures that produce a higher rate of embryo development.

(5) There are only steadily declining temperatures after October 23 and momentary peaks exceeding 16 or 16.5°C do not occur. Groves et al. (2007) were critical of the

Olson et al. (1970) study for a brief temperature uptick after test initiation in the declining temperature regimes used in their study but there is no guarantee that upticks will not occur in the Snake River.

This reasoning discounts studies on effects of constant temperature incubation with the claim that only declining temperature studies are relevant to the Snake River. Thermal effects are a result of temperature and duration of exposure. Exposure to a declining temperature can easily be parsed into successive days under a series of progressively changing exposures. If a constant temperature study shows that a temperature 16°C is harmful during a 40-day exposure, there is reason to believe that the level of harm is less with a 1-day exposure, assuming that 16°C does not result in 100% mortality in 40 days. It is possible that a 16°C temperature for a 1-day exposure has a negative effect that is small enough that to demonstrate this at $p<0.05$ would require a large sample size, something not often provided in laboratory testing. The process of setting a protective standard, as adopted by EPA, was to make use of the abundant literature available on incubation effects and to emphasize temperatures known to provide a high level of protection, not to entertain small percentages of impact. Olson et al. (1970) data show significant impacts at initial incubation temperatures in declining temperature regimes above approximately 14.4°C and possibly lower. Constant temperature studies reveal impacts at lower temperatures, notwithstanding the deficiencies pointed out meticulously by Groves et al. (2007).

p. 60. Groves et al. (2007)

test temperatures (Figures 12 and 13). However, it should be noted that a constant incubation temperature of 5.0° C (or any temperature for that matter) does not occur in nature where Chinook salmon embryos incubate.

Although it is a valid point that we must be concerned with the daily fluctuations in temperature as well as the trends in temperature (increasing and decreasing with season) and daily and seasonal minima, means, and maxima, Groves et al.'s (2007) criticism of the utility of studies on constant temperatures is unfounded. If we were to discard all constant temperature studies as invalid for application in the field because temperatures vary in nature, we would have very little data available for regulating heat loading. Moreover, in the case of the Snake River, daily temperatures do not fluctuate dramatically like they do in many other stream settings. Consequently, constant temperature experience is more appropriate in the Snake River than in smaller rivers. In addition, IPC is contemplating decline rates of only 0.2°C/d, which represents nearly constant temperature in a 5-day period.

If constant temperature data are of no value in predicting survival in the field or in setting protective standards, it is equally difficult to imagine how experiments in varying temperatures would produce greater certainty. There are an infinite number of temperature variations that could be studied. If daily temperature fluctuation were ±1°C in one experiment, then it could be criticized that this is nearly constant and does not apply to cases where temperature fluctuations are ±4°C. It is also possible that there should be a daily fluctuation embedded within a multiday decline. Temperatures in the field can also decline for several days, followed by several days of increase, followed by an overall seasonal decline. A comment such as attributed to Combs (1965) (i.e., "The conditions imposed upon the sockeye salmon eggs in these tests would rarely be duplicated in nature or in artificial propagation procedures") could as well be applied to any laboratory temperature regime set up. One objective of a constant temperature regime is to know exactly what to attribute a response to. Significant changes in mortality at specific temperature thresholds are important reasons for setting standards.

p. 62. Groves et al. (2007)

> to cooler temperatures. Finally, there was little evidence that differences in thermal adaptation existed between the two Chinook stocks. However, the authors continually brought up in their discussion the supposition that local stocks are adapted to local thermal conditions.

p. 64. Groves et al. (2007)

> the natural habitat. The authors also noted that the data provided insight as to the variation among Pacific salmon with respect to how water temperature affected embryonic development rate, survival, and fry size and weight. A very telling quote from the conclusions was, **"Because the species showed different trends in emergence timing with respect to changes in development temperature, it seems reasonable to infer that these different trends reflect adaptive variation in the species' response to environmental temperature during development"**. And finally, the authors noted, **"Population-specific differences in development can also exist, and populations that spawn in extreme environments can probably be expected to have different rates of development and survival than populations in more moderate environments"**. This paper establishes a very good base for understanding that not only are there species-specific differences in how Pacific salmon are differentially adapted to various thermal environments, but also how population-specific adaptations are likely.

Groves et al. (2007) reviewed Beacham and Murray (1989 and 1990) and concluded that population –specific adaptations are likely. Beacham and Murray (1989), according to Groves et al. found no population differences. Both Beacham and Murray papers found differences among species in development rates and other factors. Beacham and Murray (1990) cited Beacham and Murray's (1987) work on chum as showing population level differences in development rate. Even though Beacham and Murray (1990) state that population level differences in survival "can probably be expected" between extreme and moderate environments, significant population differences have not been demonstrated in the literature for any salmonid.

Groves et al. (2007) summarize the hierarchy of biological differences in this manner:

> to some extent other Chinook salmon races, are not relevant. Generally there are small differences in thermal responses among stocks and these differences increase from races, subspecies to species and then families of fishes (McCullough et al. 2001). Genetic variation exists within Chinook salmon and other salmonids of the Pacific Northwest, as indicated in classification diagrams constructed by the National Marine Fisheries Service (McCullough et al. 2001). It is clear that based on ***constant*** temperature studies, different

The hierarchy of biological responses to temperature shows finer and finer differences among taxa in a series from fish families, to species, to subspecies, to races, to populations. It is unclear whether Groves et al. (2007) intend to imply that Snake River fall Chinook are more temperature tolerant than Columbia River fall Chinook (a population difference), that fall Chinook are more tolerant than spring Chinook (a race difference), or simply that they are more tolerant than sockeye (a species level difference). Differences at the species level among Pacific salmon are not large, and differences at the population level are much smaller. Although Groves et al. are critical of constant temperature studies relative to application in field conditions, it does not appear that they would believe that constant temperature incubation studies would indicate similarity among populations where declining temperature incubation studies would reveal differences among the same populations.

Groves et al. (2007, p. 62-63)

> representative of what occurs in the natural environment cannot be stressed enough. As well, the authors acknowledge that the information provided was mainly for the accurate prediction of hatching and emergence timing, and was of practical interest for managers involved in salmon culture (hatchery environs). The basic design of this work was to

> In the end, the authors acknowledged that all of their results were based on data from constant temperature treatments, and did not reflect what would be expected to occur in the natural habitat. The authors also noted that the data provided insight as to the variation among Pacific salmon with respect to how water temperature affected embryonic development rate, survival, and fry size and weight. A very telling quote from

The authors imply that Beacham and Murray (1990) were somehow caught red-handed with a constant temperature study and had to confess that it was only relevant to hatchery environments. This is far from accurate. The authors concluded their paper with a paragraph warning of the implications of their laboratory studies, given the effects of increasing air temperatures and expected water temperature increases on salmon survival during the incubation phase. If this study only applied to fish culture, the authors would not indicate any application to the field.

Effects of Intragravel Water Temperature

g. *Effects of intragravel water temperature* – In Hells Canyon, there is a strong connection between the water column and the redd environment that allows for similar thermal conditions between the two environments. Therefore, the water column conditions provide good metrics for describing the thermal conditions of incubating embryos in Hells Canyon.

Groves et al. (2007, p. 69) reported that "The thermal environment within Chinook salmon redds can be strongly influenced by surface water conditions (Geist et al. In Press)." This statement doesn't specifically indicate that surface water temperatures would be identical to water at egg pocket depth. They also state (p. 69) that "Chinook salmon also tend to spawn where the natural down-welling of surface water into the shallow hyporheic zone occurs (Vronskiy 1972; Leman 1988; Vronskiy and Leman 1991; Geist 2000; Geist et al. 2002; Hanrahan et al. 2004)" and that Chinook predominantly use downwelling zones as opposed to all other Pacific salmon, which use upwelling areas.

Groves et al. (2007) also stated that the Hanrahan et al. (2004) study measured water column and intragravel water temperatures in spawning gravels but not in actual redd locations. This reportedly accounts for the identical temperatures found in redds vs. the warmer temperatures found in general spawning gravels. However, Figures 16-23 provided by Groves et al. (2007) to substantiate a negligible difference between surface and inter-redd water temperatures was derived from "simulated redd sites" (e.g., Groves et al. 2007, Figure 16, p. 70).

The Hanrahan et al. (2004) study shows that in the first month of egg incubation, temperatures in the shallow hyporheic zone averages approximately 0.5°C warmer than the surface water. This study also indicated that potential upwelling zones are far more common below HCD than downwelling zones. "We randomly selected 14 fall Chinook salmon spawning locations as study sites, which represents 25% of the most used spawning areas throughout the HCR." (Hanrahan et al. 2004, p. iii). If Chinook actually spawn exclusively in downwelling zones, it is likely that acceptable spawning areas are very restrictive. This makes potential spawning habitat much more scarce than anticipated. However, if spawning in upwelling areas becomes more common as the population recovers, fall Chinook would then be more subject to water temperatures warmer than surface temperatures.

Hanrahan et al. (2004) was cited as supporting that Chinook "tend" to spawn where there is natural downwelling (Groves et al. 2007). However, Hanrahan et al. (2004, p. 1.2; also see notes) state that "Recent research in the Hells Canyon Reach of the Snake River indicates that warm hyporheic water upwells into fall Chinook salmon spawning areas (Geist et al. 1999; Arntzen et al. 2001)." Also, "Where warm hyporheic water is upwelling into spawning areas within Hells Canyon, it is possible that emergence may occur 2–4 weeks earlier than in spawning areas dominated by cooler surface water." (Hanrahan et al. 2004, p. 1.2). Geist et al. (1999)(as cited by Hanrahan et al. 2004) noted that as discharge decreases as in leading up to spawning, the magnitude of upwelling increases. This appears to indicate that at the time of spawning, the availability of downwelling sites would be more limited.

I could find no statement indicating their view that spawning was predominantly in downwelling areas. It is not clear what the Geist et al. In press document has to say about the universality of spawning in downwelling zones by Chinook and whether this new information overthrows the Hanrahan et al. (2004) study on these points. Geist and Currie (2006, see notes) reported that chum tend to spawn in upwelling areas and chinook in downwelling areas below the four lower Columbia River dams. This may or may not be a universal pattern. However, to the extent that Chinook spawning occurs in upwelling areas, which would provide necessary flow velocities past incubating eggs similar to downwelling zones, a certain percentage of chinook may be incubating at temperatures greater than ambient water column temperatures.

Groves et al. (2007) state:

However, in the Snake River, temperature within the redd environment is generally the same as what is present in the water column, especially during the first few weeks following redd construction. Similar findings have been reported by Ringler and Hall (1975), Vronskiy and Leman (1991), Hanrahan et al. (2004), and Hanrahan (2007), which were based on data collected from artificial redds.

But Hanrahan et al. (2004) presented a table showing a mean temperature increase between the shallow hyporheic and ambient water column temperatures of about 0.3 to 0.5°C during the first month of incubation below HCD. Temperatures may be "generally" the same, but still a 0.3 to 0.5°C difference in mean values is biologically significant, especially when IPC is recommending initial incubation temperatures at 16.5°C when an initial temperature of 17°C results in near total mortality, based on Geist et al. (2006).

Emergence/Outmigration Timing

h. *Emergence / Outmigration Timing* - Fall Chinook salmon emerge earlier today in Hells Canyon than they did historically in Hells Canyon because of the warmer incubation conditions present today as a result of the HCC. Historically, Hells Canyon was a very cold environment and may not have been conducive for production of an Age-0 migrating fall Chinook salmon. The construction of the HCC altered the thermal regime such that emergence timing is now closer to what occurred historically in the production areas upstream of the HCC. During the 1990's, there was evidence that juvenile outmigration was delayed based on their arrival timing at Lower Granite Dam. Migration through the large slack water environment of Lower Granite Reservoir is more likely to explain the delay observed during that time. Recently, there is evidence of an earlier shift in the outmigration timing at Lower Granite. Fall Chinook salmon appear to be migrating earlier and at a smaller size than observed in the 1990's. Why this trend is occurring is uncertain, but may relate in some way to density in the rearing areas as adult returns and natural production has continued to increase.

Groves et al. (2007) state that Hells Canyon was not conducive to production of age-0 fall Chinook historically and that with construction of the HCC, the emergence timing below HCD is now closer to that in the historic main upstream production areas. So thanks to the HCC and the thermal shift and warmer winter temperatures, fall Chinook production and emigration can now follow a subyearling life history and outmigrate at close to the same time that subyearlings did historically.

Statements above about emergence/outmigration timing imply that:
(1) emergence timing below HCD is close to the historical timing from the Marsing Reach upstream
(2) delayed migration timing occurred in the 1990s but is no longer an issue
(3) the slack water of Lower Granite Reservoir is to blame for the delayed emigration
(4) there is a recent trend toward earlier emigration timing.

There are a number of reasons why these statements may not be accurate and making all these assumptions places fall Chinook at risk.

(1) IPC rightfully criticizes the Snake River TMDL process for not considering the significant impact of upstream human activities in altering the thermal regime of the inflow to Brownlee Reservoir. Much of this thermal impact is undoubtedly attributable to upstream IPC projects. Because IPC is so cognizant of the massive changes in temperature of the Snake River, it would seem that it would also recognize the linkage between spawn timing and emergence timing and spawn timing and water temperature. If historic temperatures were altered by human activities dating at least from 1900 and we have only crude estimates of emergence timing from the 1950s, it stands to reason that emergence timing prior to 1900 could have been significantly different.
(2) Hanrahan (2004, p. 1.1) stated that fall Chinook emigrants from below HCD arrive at Lower Granite Dam 1 to 4 weeks later than before the HCC. Hanrahan et al. (2004) state that there is a significant survival advantage to early emigrants because they can avoid the high mid-summer Snake River mainstem temperatures by their earlier migration timing. This implies that there may be a further advantage in an earlier migration timing achievable with better temperature control and earlier spawning.
(3) If the slack water is to blame, IPC has a responsibility to utilize its cold water and its available flow volume at Brownlee Reservoir to adjust temperatures (lower in summer and fall; warmer in winter).
(4) The recent trend toward earlier emigration is largely a product of the age-1 life history that has been produced in the Clearwater River. The Clearwater River was historically not a major fall Chinook producer. The cold waters from this river during the summer due to the releases from Dworshak have created slower summertime growth and the need for overwintering and emigration as 1-year-old smolts in the spring. This artifact of addressing the warm water problems associated with the lower four Snake River dams should not be confused with the problems created by the HCC.

Groves et al. (2007, p. 78).

> rearing and emigration. In the recent past, up to 50% of the subyearling smolts from the upper reach of the Snake River passed Lower Granite Dam by early July, whereas historically it was believed that they were completely out of this reach by the end of June. This apparent delay in emigration is often attributed to later emergence timing than to what is believed to have occurred historically when production was in the Swan Falls Reach.
>
> A more meaningful comparison relative to the effect of the HCC on emergence and emigration timing is to compare pre-Hells Canyon Complex temperatures of Hells Canyon to present day temperature of Hells Canyon. This comparison indicates that the Hells Canyon Complex warmed the incubation environment such that emergence timing today in Hells Canyon is much earlier relative to what it was pre-HCC. Further, post-HCC temperatures are much closer present-day to the historic Swan Falls spawning area.

It is admitted that 50% of the subyearling smolts pass Lower Granite Dam after July, which is during the warmest-water period and results in high mortality. Despite this, it is also stated that this migration timing is better than we would have expected for this portion of the Hells Canyon Reach prior to construction of the HCC. If this is so, we are to simply accept the loss of over 90% of the historic production and in return get a minor improvement in timing for the remaining portion of the run which never was good habitat. This minor improvement in timing, further, likely comes with the tradeoff of higher mortality in the incubation phase if initial temperatures would be pushed to 16.5°C. Global warming that can easily cause further water temperature increases in the Snake River would not be safeguarded under the IPC proposal, but would be chalked up to "unforeseen" climatic extremes. NOAA Fisheries' recovery plan depends heavily on improvement to the habitat, yet IPC intends to make no improvements in water quality in excess of the minimum requirements of the CWA, and further intends to contest even these standards as not being lenient enough.

Groves et al. (2007, p. 80)

> 2. The presence of the HCC has also created warmer over-winter base temperatures in the area below Hells Canyon Dam relative to the pre-development era because of the large volume of 4°C water stored in Brownlee Reservoir over the winter months.

Emergence timing can be controlled by regulation of spawn timing and the temperature regime during the entire incubation period. Currently, temperatures during the fall have been shifted by approximately 3 weeks to later in the season. This likely has caused a later spawn timing. In addition, winter temperatures are cold below HCD. IPC claims that emergence timing has benefited below HCD by the HCC operations, there is additional room for significantly advanced emergence by use of a TCS. For example, the winter temperatures in 2002 have a prolonged period of temperatures from approximately 2.16 to 3.5°C (McCullough, see figure in notes produced from IPC raw data). If Brownlee Reservoir is stratified during the winter with the deepest portions of the reservoir holding the densest water at 4.0°C, it would be possible to effectively raise this water to run through the turbines. Bubbling to mix water at the face of the dam would not be so effective a means to accomplish a transfer of 4°C water downstream because it tends to mix this water with colder surface water.

Juvenile fall Chinook need to rear as they migrate downstream. For those late migrants entering the Snake River downstream of HCD, it shoreline temperatures exceed 18°C, the juveniles tend to avoid rearing along the shore (USACE, Appendix K, see notes). Marginal temperatures tend to be greater than temperatures in mid-channel. However, mid-channel growth opportunities (i.e., food availability) would be expected to be lower than along the shoreline. Consequently, late migration under high shoreline temperature conditions would probably reduce the ability of these fish to grow adequately.

Ehist

Groves et al. (2007, p. 7)

Data for any particular year may not be complete. When data were incomplete, IPC substituted data from a similar water year or a lower water year. IPC believes this is a conservative assumption as conditions, flow and temperature, would be more critical in a lower water year. For example, if Salmon River daily average temperature was unavailable for 1994, Salmon River daily average temperature from another low-water year, like 1992, was used to develop a complete data record. The logic sequence used to develop complete data records for the EHist temperature analysis is described in Table 2.

Although the plots from Ehist look reasonable, the methodology described above for filling in missing data appears to be flawed. It is stated that missing data were replaced by data from a similar flow year. Presumably a regression exists for flow vs. temperature in one year that can then be applied to flows in the year where water temperature data are missing. However, the water temperature is also a function of air temperature and solar radiation over a number of days preceding the day of water temperature measurement. Data provided by IPC do not indicate which days had synthesized data.

Ehist graphs taken from the Snake River TMDL (Figures 6.1-3, 6.1-4, 6.1-5, 6.1-6) and reproduced in Groves et al. (2007) show that on October 1, 2002, the Ehist Brownlee inflow is 13°C, which is identical to the measured inflow temperature. However, the measured HCC outflow on this date is 18°C. This means that the HCC causes a 5°C increase in water temperature that is in effect until mid-November. This is the thermal shift problem that likely causes a shift in spawning time, incubation survival, or both. If the measured inflow to Brownlee is 13°C on October 1, yet the HCC measured outflow is 18°C, it appears that the HCC causes a significant warming (i.e., 5°C), whereas IPC claims a freedom to warm the river by only 0.5°C.

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Abstract.—The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon Oncorhynchus tshawytscha were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20°C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–7°C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

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Progress Report

**Effects of Water Temperature Exposure on Spawning Success and Developing Gametes of
Migrating Anadromous Fish - 2004**

Study Code: ADS-00-05

by

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Abstract

Examinations into the effects of high sub-lethal water temperature exposures on the reproductive success of migrating anadromous fish were preformed. Investigations included analysis of migration success and the subsequent embryo viability of steelhead and fall Chinook salmon. Radio telemetry methods were used to study migration patterns related to temperature, while viability tests were completed at Lyons Ferry, Nez Perce,

and Dworshak Hatcheries. One hundred steelhead and one hundred Chinook salmon were tagged at Ice Harbor Dam from July 2 to September 30, 2004. We recovered 88 of 200 external and 45 of 108 internal temperature tags released. Included in these, we recovered both the external and internal temperature tags from 15 steelhead and 15 Chinook salmon. Comparisons between these showed that internal body temperature tracked external water temperature closely. Chinook salmon were exposed to temperatures as high as 23.6°C, and had total migration temperature exposures as high as 19.2 degree days above 20°C and 60.0 degree days above 18°C. Steelhead experienced temperatures maximum temperatures of 24°C and had total migration temperature exposures as high as 15.7 degree days above 20°C and 48.8 degree days above 18°C. Migration temperature exposures were highly correlated with release date and the temperature at Ice Harbor Dam at the time of passage. Embryo mortality was tracked for thirty Fall Chinook, and ranged from 1.11% to 19.84%, though one brood exhibited losses over 99% due to soft shell disease. Total embryo mortality was tracked for six steelhead, and ranged from 5.67% to 81.21% with steelhead generally having higher losses than fall Chinook. Embryo mortality data in relation to temperature exposures were analyzed for 13 Chinook salmon. The five fish with the highest temperature exposures above 20°C exhibited five of the six highest embryo mortalities at the eye up stage and the button up stage. A similar, but weaker, relationship was observed when temperature exposures were calculated using an 18°C threshold.

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Technical Report 2006-4

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ASSOCIATIONS BETWEEN ADULT SALMON AND STEELHEAD BODY TEMPERATURE DURING UPSTREAM MIGRATION AND ESTIMATED ENVIRONMENTAL TEMPERATURES IN LOWER GRANITE RESERVOIR DURING COLD WATER RELEASES FROM DWORSHAK RESERVOIR, 2001-2002

Report for study APS-00-5
under contract DACW68-01-R0008
Task order No. 001
by

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for
U.S. Army Corps of Engineers
Walla Walla District
2006

Cool-water releases from Dworshak may have conferred a benefit to upstream migrating adults because during warm water temperatures salmonids face an increased risk of disease, decreased swimming performance, increased energetic costs, and decreased gamete production and viability. Colgrove and Wood (1966) reported outbreaks of *Chondrococcus columnaris* in Fraser River sockeye salmon populations in which warm temperatures played a role. Swimming activity used 84% of total energy consumed by upstream migrating sockeye salmon in the Fraser River and areas of difficult passage (Hell's Gate) and elevated water temperatures (21 °C) were energetically costly (Rand and Hinch 1998). Warm temperatures can delay ovulation (Taranger and Hansen 1993) and cause molecular changes in egg development (Jobling et al. 1995; King et al. 2003). DeGaudemar and Beall (1998) found overripening of gametes in Atlantic salmon where egg retention, egg mortality, egg infertility, and egg malformation increased significantly with the number of days past ovulation. Low hatch rate (42% compared to 84% of other stocks) of coho salmon from the Fairview stock in Lake Erie was thought to be due to warm water temperatures affecting ovulation and egg maturation (Flett et al. 1996). Coldwater refuges for fish are becoming a vital element in the survival of salmonids during migration as mean water temperatures increase with changing climate, water- and land-use practices. Changes in the hydrograph and increasing temperatures have caused run timing changes in anadromous fish (Quinn and Adams 1996). Robards and Quinn (2002) found changes in patterns of summer run steelhead in the Columbia River over the past six decades where the bimodal distribution of the early and late run have become closer together and less apparent. With increasing temperatures due to global warming fish habitat will be lost (Keleher and Rahel 1996). Conditions in the Klamath basin for salmonids have deteriorated where it is estimated that temperatures have been increasing by 0.5 °C per decade since the 1960's and the average length of mainstem river with cool summer temperatures has decreased by 8.2 km per decade (Bartholow 2005). Based on one global warming model, Meisner (1990) estimated that increases in temperature in two southern Ontario streams would move thermal barriers causing 30 to 40% habitat loss for brook trout. Several studies have found fish use pools, groundwater discharge, and tributary inflows as thermal refugia (Snucins and Gunn 1995; Biro 1998; Torgersen et al. 1999; Baigun 2003; Baird and Krueger 2003; Goniea et al. 2006; High et al. 2006). Rainbow trout in northeast Oregon streams were found in coldwater patches that were 3 to 8 °C colder than ambient stream temperature from groundwater discharge when temperatures ranged from 18 to 25 °C (Ebersole et al. 2001). Adult and juvenile steelhead in Northern California were found in stratified pools that were 3.5 °C cooler than ambient stream temperatures (Nielsen et al. 1994). In an analogous fashion, adults migrating through the study reach of the Snake River used the cool water created by the Dworshak releases. Interestingly, in the Clearwater River and near the confluence, individuals selected warmer than average water temperatures when mean available model temperatures were below the preferred temperatures reported in the literature (Figure 36). Similarly, Matthews et al. (1994) found rainbow trout and brown trout using stratified pools for thermal refuge in the North Fork of the American River, CA, though fish were not found using the coldest available water.

p. 68.
Overall the results and available literature suggest that migrating adult salmon and steelhead find, use, and benefit from the cooler water that is available in Lower Granite Reservoir during the cold water releases from Dworshak Dam. Consequently, management of Dworshak releases should account for the effects of the releases on adult salmonids as well juveniles. Importantly, there are few potential thermal refuges in the lower Snake River (e.g. cold-water tributaries), highlighting the potential benefit of the Dworshak releases to summer- and fall-run adult salmon and steelhead in the lower Snake River.
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T.P. Quinn.
1991.
Behavioral thermoregulation and homing by spring chinook salmon, Oncorhynchus tshawytscha (Walbaum), in the Yakima River.
J. Fish Biology 39:301-312.
Temperature-sensitive radio transmitters were employed to study the patterns of behavioural thermoregulation, habitat preference and movement of 19 adult spring chinook salmon, *Oncurhynchus tshawytscha* (Walbaum), in the Yakima River. During the 4 months prior to spawning, fish maintained an average internal temperature 2.5°C below ambient river temperature. This represented a 12 to 20% decrease in basal metabolic demand or a saving of 17.3 to 29.9 calkg^{-1} h^{-1}. Fish were most commonly associated with islands, pools, and rock out-croppings along stream banks. Homing behaviour appeared to be modified to optimize temperature regimes and energy conservation. As the time of spawning approached, fish left thermal refuges and migrated to spawning grounds upstream and downstream of refuge areas. Although spring chinook salmon residing within cool-water refuges may be capable of mitigating sub-lethal temperature effects, cool-water areas need to be abundant and available to the fish. The availability of suitable thermal refuges and appropriate holding habitat within mainstem rivers may affect long-term population survival.

Monitoring Adult Chinook Salmon, Rainbow Trout, and Steelhead
in Battle Creek, California, from March through October 2001
USFWS Report
Prepared by:
Matt R. Brown
Jess M. Newton

Holding location.—Monitoring results indicate Chinook held in Battle Creek for about 4 months (from early June through early October) prior to spawning. Barrier weir monitoring showed that 75% of unclipped Chinook migrating into Battle Creek had passed the weir by 7 June. Stream surveys indicated that most Chinook did not spawn until early October (see below). Therefore, we considered survey observations made during July, August, and September to be during the holding period for spring Chinook in 2001.

Spawning of potential spring Chinook may have been delayed as 95% of upper Sacramento River spring run are reported to spawn by mid-September (Vogel and Marine, 1991). On Mill Creek, the peak of spawning activity for spring Chinook was estimated to be the last week of September and the first week of October (Harvey Arrison, 2001). In Battle Creek, in previous years with better water temperatures, spring Chinook began spawning by mid-September (RBFWO, unpublished data). In 2001, Chinook holding in the South Fork may have delayed spawning because of unsuitably high water temperatures and low flows. We observed redds in the South Fork being built progressively farther downstream as the spawning season progressed. We observed the first redd in the coolest water immediately below Coleman Diversion Dam (rm 2.5) on 18 September. At this time water temperatures for egg incubation were rated as fair at the dam but very poor (lethal) downstream at Manton Road Bridge (rm 1.7). By the following survey on 3 October, water temperature ratings had upgraded to good at the dam and poor at the bridge and we observed new redds midway between the dam and the bridge. On 16 October, our next survey, water temperatures at the bridge were rated as good for egg incubation and we observed a new redd just downstream of the bridge. Because spawning of potential spring Chinook holding in the South Fork was delayed, their progeny would likely be mis-classified as fall Chinook juveniles according to length criteria commonly used for upper Sacramento River juvenile Chinook. Overall, water temperatures in 2001 were adequate for spring Chinook to successfully produce juveniles but at a reduced number due to temperature-dependant spawner and egg mortality.

Our detection rate of live adult Chinook by stream surveys may have been higher on the South Fork than on other reaches. Based on redd observations, we estimate a total spawning population of 64 and our highest count of live Chinook during monthly stream surveys was 27. Yet, when considering the South Fork only (Reach 3), redd-based estimates and survey counts are much closer; 24 and 17, respectively. As noted previously, differences in flow and geomorphology between reaches may be responsible for differences in detection rate.

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Venditti, David, Catherine Willard, Chris James, Paul Kline, Dan Baker, "Captive Rearing Program for Salmon River Chinook Salmon", 2002 Annual Report, Project No. 199700100, 73 electronic pages, (BPA Report DOE/BP-00004002-4)

Chilled Water Experiments

A common thread linking previous releases of captive-reared Chinook salmon has been that these fish have consistently spawned several weeks later than their naturally produced counterparts (Hassemer et al. 1999, 2001; Venditti et al. 2002, 2003). In order to address this shortcoming, additional water chilling capacity was added at Eagle in 2001 to assess if water temperature manipulations between the time maturing adults were returned to freshwater and release could be used to advance their spawn timing. While we could find no instances where this has been tested on Chinook salmon, there is a substantial amount of literature describing the effect of temperature on the timing of ovulation in other salmonid species. Elevated holding temperature prior to spawning has been shown to retard the onset of ovulation in rainbow trout O. mykiss (Pankhurst et al. 1996; Pankhurst and Thomas 1998; Davies and Bromage 2002), pink salmon O. gorbuscha (Beacham and Murray 1988), Atlantic salmon (Taranger and Hansen 1993), and Arctic charr Salvelinus alpinus (Gillet 1991; Jobling et al. 1995). However, Henderson (1963) did not observe this relationship in eastern brook trout S. fontinalis.

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Upon reaching spawning areas, adult female Chinook salmon excavate shallow oval shaped depressions in appropriate gravel beds. The depressions, or nests, are known as redds. The general belief is that each female Chinook salmon constructs multiple redds, but observational data suggest one redd per female is most typical (Crisp and Carling 1989; Neilson and Banford 1983). Spawning occurs over several days, during which the female deposits up to five groups, or pockets, of eggs into the redd and then covers them with gravel (Healey 1991).

The specialized life history of salmon restricts flexibility in the duration and timing of the spawning cycle. Spawning salmon are temporally constrained, and regardless of whether conditions are conducive to spawning, they eventually will spawn or die. For example, during unseasonably warm years, salmon may spawn well outside reported preferred, optimal, or suitable water temperature ranges. Therefore, caution should be used in the interpretation and application of water temperature index values derived from observations of spawning Chinook salmon.

2.11 PRE-SPAWN MORTALITY

For purposes of this report, pre-spawn mortality is defined as the proportion of females in the spawning escapement that dies prior to spawning. Typically, pre-spawn mortality estimates are based on carcass survey data relying on direct observation of carcass ovaries. The factors responsible for pre-spawn mortality are poorly understood, although water temperature and disease appear to be significant contributors (Healey 1991; McCullough 1999). Isolating the degree of influence that water temperature and disease have on pre-spawn mortality rates is difficult because water temperature and disease are likely only contributing factors. For example, spatial and temporal variation in ocean conditions can strongly influence the physical condition of migrating salmonids. Migrating salmon in poor condition are affected to a higher degree when exposed to stressful conditions, and are more likely to die prior to spawning. Salmon in poor condition also are more susceptible to disease. Salmon that die unspawned represent an important loss to egg production, and potential decreased escapement in subsequent years. Pre-spawn mortality rates are usually low, but can vary across regions and through time. Shepard (1975) *in* Healey (1991) reported a 19.1 percent pre-spawn mortality estimate for Bear River Chinook salmon, and that 30 of 230 female Chinook salmon in the Babine River died unspawned. In 1965, approximately 25 percent of Chinook salmon in a spawning channel at Priest Rapids, Washington, died prior to spawning, reportedly due to a protozoan infection of the gills (Pauley 1965, as cited *in* Healey 1991). In 1988, DFG reported that in the Trinity River, pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawning season, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001).

6.6 PRE-SPAWN MORTALITY

Pre-spawn mortality estimates in the lower Feather River from 2000 through 2003 were high when compared to reported estimates from some other systems. Observer bias may account for a small fraction of the high estimates because of the subjective nature of the protocol, however there are likely other contributing factors. In 1988, DFG reported that in the Trinity River pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawn, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River reportedly ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001). Pre-spawn mortality rates reportedly were 60 percent and 87 percent on Battle Creek in 2002 and 2003, respectively (pers. comm., C. Harvey-Arrison, 2004). In the lower American River, 2003 pre-spawn mortality reportedly was at least 37 percent, and could possibly be higher if partially spawned fish are included (Healey 2004). Pre-spawn morality in the Yuba River, however, was reported to be less than 4 percent in 2003 (pers. comm., S. Theis, 2004). T. Heyne (2004) reported that prespawn mortality rates in tributaries to the San Joaquin River (Tuolumne, Stanislas, and Merced rivers) typically are 5 percent or less. In the Sacramento River, pre-spawn mortality for fall and late-fall-run Chinook salmon were as high as 13 percent in 1996, but was between 3 percent and 8 percent in other years (Snider et al. 1999; Snider et al. 2000). From 2000 through 2003, the pre-spawn mortality estimate in the LFC and HFC averaged approximately 42.5 and 39.7 percent, respectively. The average prespawn mortality rate combining all study years and both reaches was approximately 41.1 percent. For all years and both reaches, 70-100 percent of carcasses inspected in the first four weeks

(September 2 through October 4) were determined to have died prior to spawning. The high estimates during the beginning of the spawning period are of particular concern because federally threatened CV ESU spring-run Chinook salmon may contribute to the initial spawners. The Feather River Hatchery designates all adult salmon arriving up to October 1 as spring-run Chinook salmon, and all fish arriving after October 1 as fall-run Chinook salmon (DFG 1998b). The general belief is that hatchery fish are less genetically fit, and are more susceptible to stressors than are wild fish (Reisenbichler and McIntyre 1977, as cited by McCullough 1999). If this is the case, then it may be that most of the pre-spawn mortality in September in the lower Feather River is attributable to the less resistant hatchery spring-run Chinook salmon. In 2000, 2001, 2002, and 2003, the percentage of inspected carcasses that had an adipose fin clip was approximately 3.1 percent, 4.7 percent, 7.9 percent, and 6.8 percent, respectively. For all years combined, the percentage of inspected carcasses that had an adipose fin clip was 5.6 percent. The percentage of inspected carcasses that had and adipose fin clip in September in 2000, 2001, 2002, and 2003 was approximately 9.2, 12.5, 16.3 percent, and 12.4 percent, respectively. The Feather River Hatchery does not clip all hatchery reared Chinook salmon released into the lower Feather River. The origin of non-clipped salmon is therefore uncertain. Hankin (1982) suggested implementation of several hatchery practices that would allow the discrimination of wild and hatchery fish, most notably for hatcheries to distinctly mark a constant proportion of releases from year to year. Hankin (1982) stated that annual variation in marking proportions rules out later discrimination between returns of hatchery and wild fish. Data from the Feather River Hatchery concerning the proportion of releases distinctly marked were unavailable, but it is unlikely the proportions were constant during those years that would affect the results from this study. Therefore, estimating the proportion of pre-spawn mortality accounted for by naturally spawned spring-run Chinook salmon in the lower Feather River, given available data, is not possible.

2.2.4 Temperature and Habitat Use

Temperature appears to regulate the duration of shoreline residence and downriver movement of the fish. Subyearlings appeared to be distributed primarily along the shoreline of the reservoir during their early rearing period in the reservoirs and pelagically oriented once shoreline temperatures exceed 64 to 68 °F (18 to 20 °C). Based on results from 1987, 1990, 1991, and 1992, duration of littoral rearing was longer in the cooler years [*i.e.*, producing higher runoff flows (Curet, 1993)]. Littoral rearing differed from 48 days in 1992 to 84 days in 1991. In 1990 and 1991, when shoreline temperatures remained below 64 °F (18 °C) until mid to late June, subyearlings remained along the shoreline until late June. Peak abundance along the shoreline of the reservoir occurred in late May to early June, 2 weeks later than in 1987 and 1992, which were lower flow years of more rapidly warming shoreline temperatures. As increasing water temperatures result in water too warm for shoreline rearing, subyearlings may move offshore into deeper, faster areas where they rear until commencing their downriver migration.

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Connor, W.P., J.G. Sneva, K.F. Tiffan, R.K. Steinhorst, and D. Ross. 2005. Two Alternative Juvenile Life History Types for Fall Chinook Salmon in the Snake River Basin. Transactions of the American Fisheries Society 134:291-304.

Summer flow augmentation provides the highest level of protection for the later-migrating fall Chinook salmon juveniles that are most likely to exhibit the reservoir-type juvenile life history (Connor et al. 2002, 2003c). Given the lack of thermal refuge in the contemporary spawning areas, mortality of these later-migrating fish would be high without summer flow augmentation (range of estimates, 78–87%; Connor et al. 2003c). Therefore, we believe that the reservoir-type juvenile life history is a successful response to large-scale changes in historical habitat that has been enabled or at least enhanced by summer flow augmentation. We also suggest that the decision by managers to save some water in July and August for release in September should further enhance the reservoir-type juvenile life history, provided this decision does not result in temperatures above 20°C in Lower Granite Reservoir during July and August.

Salinger, D.H. and J.J. Anderson. 2006. Effects of Water Temperature and Flow on Adult Salmon Migration Swim Speed and Delay. Trans. Am. Fish. Soc. 135(1):188-199. The effects of temperature and flow on the migration of adult Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* through the Columbia River hydrosystem were determined with a novel technique that fits a broken linear model of swim speed versus temperature and flow by partitioning data into speed ranks. Using the migration times of passive integrated transponder (PIT)–tagged adult Chinook salmon upstream between Bonneville and Lower Granite dams (462 km) over the years 1998–2002, we found that a maximum swim speed of about 1 body length/s occurred at 16.3°C. Speed was less above and below this optimum temperature. For PIT-tagged steelhead, migration speed uniformly decreased with increasing temperature, suggesting that the fish migrated at temperatures above the optimum. Migration delay was also a unimodal function of temperature, the minimum delay occurring around 16–17°C. The broken linear model was compared with seven alternative models of unimodal and monotonic speed versus temperature and flow. The unimodal models fit the data better than the monotonic models (when ranked by the Akaike information criterion), and the broken linear model fit the data best. Flow was insignificant in all of the monotonic models and only marginally significant in the unimodal models. The findings of this study have significance in evaluating the effects of hydrosystem operations and climate change on salmon and steelhead fitness.

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Berejikian, Barry, "Research on Captive Broodstock Programs for Pacific Salmon", 2004-2005 Annual Report, Project No. 199305600, 162 electronic pages, (BPA Report DOE/BP-00017690-1.

survival. Combined with pedigree analyses that estimate individual reproductive success, the ability to quantify spawning frequency and spawn timing of individual fish will improve estimates of natural selection on those characters. For example, adult salmon may experience selective mortality after reaching the spawning grounds and fail to spawn (Quinn and Kinnison 1999). Spawn timing affects emergence timing and may consequently affect offspring growth and survival (Einum and Fleming 2000). Observing or remotely detecting actual spawning events in natural streams would replace less precise surrogate estimates of spawn timing such as migration timing (Seamons et al. 2004).

There is growing evidence that rearing temperatures can alter the timing of spawning as well as gamete quality (e.g. Taranger and Hansen 1993; Pankhurst et al. 1996; Pankhurst and Thomas 1998; Taranger et al. 1999; King and Pankhurst 1999; Davies and Bromage 2002). Preliminary studies with Snake River spring Chinook salmon have shown that chilling fresh water during the final months preceding spawning achieves a slight advancement of spawning time (Venditti et al. 2003). Extensive studies on Atlantic salmon have shown advancement of spawn timing and improvements in egg quality with reduced water temperatures (e.g. King et al. 2003). Given that rearing temperatures for captive Snake River spring Chinook salmon in the captive broodstock programs may be several degrees higher than they would experience in the ocean and river during the upstream migration, it is plausible that rearing temperatures may underlie some of the reproductive problems. Therefore, an experiment is being conducted to examine the effects of reducing rearing temperature for 12 months in seawater and 2 to 4 months in fresh water on reproductive performance of spring Chinook salmon. Since there may be stock differences in response to temperature, two stocks of fish are being used in this experiment.

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Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures

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Abstract.—The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon *Oncorhynchus tshawytscha* were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20°C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–7°C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

Richard S. Brown and David R. Geist. 2002. Determination of Swimming Speeds and Energetic Demands of Upriver Migrating Fall Chinook Salmon (*Oncorhynchus tshawytscha*) in the Klickitat River, Washington. PNNL-13975. Submitted to Bonneville Power Administration. Project Number 22063, Contract 42663A.

The study also examined energy costs and swimming speeds for fish released above Lyle Falls as they migrated to upstream spawning areas. This journey averaged 15.93 days to travel a mean maximum of 37.6 km upstream at a total energy cost of approx 3,971 kcals (34% anaerobic and 66% aerobic) for a sample of five fish. A bioenergetics example was run, which estimated that fall chinook salmon would expend an estimated 1,208 kcal to pass from the mouth of the Columbia River to Bonneville Dam and874 kcals to pass Bonneville Dam and pool and the three falls on the Lower Klickitat River, plus an additional 2,770 kcals above the falls to reach the spawning grounds, leaving them with approximately 18% (1,089 kcals) of their original energy reserves for spawning. Results of the bioenergetics example suggest that a delay of 9 to 11 days along the lower Klickitat River may deplete their remaining energy reserves (at a rate of about 105 kcal d^{-1}) resulting in death before spawning would occur.

Note: if a 9-11 day migration delay risks death to Klickitat fall Chinook, the extensive delays and fallback rates on the Snake River are likely to cause more serious mortalities, bioenergetic stress, and inability to delay spawning time to accommodate the 3-week shift in temperature peaks.

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- Richards, M. 1959. Snake river fall Chinook spawning ground survey, 1959. Idaho Department of Fish and Game.

SNAKE RIVER FALL CHINOOK SPAWNING GROUND SURVEY, 1959

DISEASE

During the 1958 survey, a relatively large number of fish was observed to have lesions typical of columnaris. This condition was again observed early in the 1959 survey and, during the remainder of the survey, fish bearing lesions typical of columnaris, in sample, were recorded. The sample was limited to carcasses fresh enough that accurate determinations could be made and to carcasses checked by a qualified observer.[1] A sample of 74 dead fish showed the typical lesions to be present in 77.0 per cent of the fish sampled. Of 53 dead fish sampled and classified as to size and sex, 100 per cent of the adult males and of the females and 63.3 per cent of the jacks had lesions typical of columnaris.

Table 1.--Fall chinook salmon counts, by month, Brownlee Dam, 1957 and Oxbow Dam, 1958 and 1959

Month	1957	1958	1959
August	63	1	27
September	3,517	4,732	6,043
October	10,686	9,285	5,694
November	643	60	66
December	43	0	0
Totals	14,952	14,078	11,830

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Idaho Department of Fish and Game. 1960.

SNAKE RIVER FALL CHINOOK SPAWNING GROUND SURVEY 1960

A sample of 37 dead fish showed typical gill lesions to be present in 62.2 per cent of the fish samples. Number and per cent of sampled fish with gill lesions typical of columnaris, by sex and by size classification for males, are shown in Table 7.

A total of three fish were found with characteristic symptoms of furunculosis.

Based on the spawning ground sample, jacks (assumed two-year old fish) comprised 15.1 per cent of the 1960 run. Because of fluctuating sizes of

Table 9.--Comparison of size of parent run and calculated number of returning two-year old fish, Snake River fall chinook, 1957-1960

Year	Parent run redd count	Year	Fish counted at Brownlee-Oxbow Dams	Spawning ground jack percentage	Calculated no. of returning two-year old fish
1955	513	1957	14,952	31.9	4,770
1956	268	1958	14,078*	13.7	1,929
1957	2,656	1959	11,830	50.3	5,950
1958	993	1960	5,131	15.1	775

Table 1.--Fall chinook salmon counts, by month, Oxbow Dam, 1960

Month	1960
August	56
September	3,266
October	1,462
November	125
December	2
Total	4,911*

A THREE YEAR STUDY
OF FALL CHINOOK SALMON SPAWNING AREAS
IN SNAKE RIVER ABOVE HELLS CANYON DAM SITE

by

Paul D. Zimmer
Fishery Management Biologist

July 1950

Report
of
FISH AND WILDLIFE SERVICE
Region 1
Portland, Oregon
Leo L. Laythe, Regional Director

p. 10.

14. Boat observations conducted in October were very unsatisfactory for several reasons. The nearness of the observers to the water, which restricted their vision to about ten feet on either side of the boat, the rapid speed of travel over the riffle areas, and the strong winds and overcast sky all contributed to make an accurate count of nests impossible. In contrast to this it was found that aerial observations were not seriously affected by the strong winds, overcast sky or any of the other factors that had so influenced the boat survey. Because of the exceptionally clear water which prevailed throughout the entire period of aerial observations all nests were clearly visible to the aerial observer at the time of the November count. It was considered that the total nests counted on November 6 represented all of the spawning which had previously occurred. [illegible]

- p. 11

Table 3. SUMMARY OF SPAWNING-BED OBSERVATIONS OF 1947

Date	Section of River Examined	Visibility in water	Number of Nests observed 1/	Method of Counting Nests	Hours Spent in Observation
Oct. 3	Vicinity of Murphy Bridge	Poor	3	From bank	6
Oct. 15	Swan Falls to Murphy Bridge	Poor	73	Boat	8
Oct. 17	Murphy Bridge to 10 miles above Marsing Bridge	Poor	0	Boat	8
Oct. 17	Swan Falls to Marsing Bridge	Excellent	1390	Plane	3
Oct. 17	Marsing Bridge to Weiser	Excellent	0	Plane	3
Nov. 6	Swan Falls to Murphy Bridge	Excellent	3311	Plane	3
Nov. 6	Murphy Bridge to Marsing Bridge	Excellent	483	Plane	2
Nov. 6	Marsing Bridge to Weiser	Excellent	10	Plane	2

p. 17.

20. Shortly after October 18, 1949, the river cleared up and the nests made from then until November 22, the date of the second survey, were free of silt and readily distinguishable from those made earlier. On the date of the latter survey only those nests were counted which were clearly defined and considered to have been made after October 18. Total nests counted in 1949 was 348, Table 5.

p. 18.

Tab;e 5. SUMMARY OF SPAWNING-BED OBSERVATIONS OF 1949

Date	Section of River Examined	Visibility in water	Number of Nests observed 1/	Method of Counting Nests	Hours Spent in Observation
Oct. 18	Swan Falls to Murphy Bridge	Fair	148	Plane	2
Oct. 18	Murphy Bridge to Marsing	Fair	13	Plane	1
Oct. 18	Marsing to Weiser	Fair	0	Plane	3
Nov. 22	Swan Falls to Murphy Bridge	Good	144	Plane	2.5
Nov. 22	Murphy Bridge to Marsing	Good	38	Plane	2
Nov. 22	Marsing to Weiser	Good	5	Plane	3

SUMMARY

27. Excellent spawning and rearing conditions for fall chinook salmon are present in the section of Snake River between upper end of Hells Canyon and Swan Falls, Idaho.

28. It appears from the information available that the spawning period of fall chinook salmon in the Snake River above Hells Canyon Dam site starts in late September or early October and is completed by early December.

- - - - - - - - - -

Olson, P.A.,
R.E. Nakatani, and T. Meekin.
1970.
Effects of thermal increments on eggs and young of Columbia River fall chinook. Battelle Memorial Inst., Pac. Northwest Lab. Rep. BNWL-1538, Richland, WA. 23 p. + 8 tables and 25 figures [QL 639.25, .E4441 1970]

Series III (November 23 Spawning)

The apparent tolerance of this series to high temperature increments was greater than the preceding two because of the rapid decrease of Columbia River temperatures during the winter. Increments as high as 10.8 °F resulted in low total mortalities of 10.3 percent, well within the range of normal hatchery production. Excessive mortalities were evident only at the greatest increment tested (12.8 °F). An addition of 2 °F over the 10.8 °F increment of Lot 6 resulted in a drastic mortality increase. Total mortalities revealed an erratic pattern that was inconsistent with increasing temperature increments up to 10.8 °F. Statistical tests reflected the erratic results since mortalties of Lot 5 (+8.8 °F) were not significantly greater than Lot 1, whereas losses in the other lots (Lots 2,3 and 4) showed significantly greater mortalities. Although temperature levels in these lots resulted in generally low mortalities even with thermal increments as great as 10.8 °F, the erratic pattern showed no consistent trend over this temperature range.

p. 17.

Because of falling river temperatures after the start of the initial experiment, successively later series tolerated greater thermal increments. Temperatures 7.0 °F in excess of base river temperatures resulted in excessive mortalities in Series I (spawned Oct. 30) and 12.0 °F resulted in total mortality. However, a 12.5 °F increment above river temperatures in Series IV (spawned Dec. 8) produced a mortality of only 12.4%, well within the range of normal hatchery production. Temperature increments averaging 2.9 to 2.8 °F for Series I and II (spawned Oct. 30 and Nov. 14) and 6.5 °F for Series IV (spawned Dec. 8) did not significantly increase either total or fish mortalities over the coldest lots experiencing normal base river temperatures. Experimental temperatures that produced no significant increase in the mortality of these three series are shown in Figure 25. Data from Series III (spawned No. 23) were not used because of erratic and hard-to-relate mortality-temperature correlations.

p. 18.

egg mortalities also experienced greater losses during the fry stage. Under cooler, but still adverse temperature treatments, egg and fry mortalities were not obviously greater, but increased losses occurred primarily during the critical transition period at commencement of active feeding. Once the

Hanrahan, T.P.,
D.R. Geist, E.V. Arntzen, and C.S. Abernethy.
2004.
Effects of Hyporheic Exchange Flows on Egg Pocket Water Temperature in Snake River Fall Chinook Salmon Spawning Areas.
PNNL-14850, Pacific Northwest National Laboratory, Richland, WA.

p. 1.1.

Prior to the construction of the Hells Canyon Complex of dams on the Snake River, fall Chinook salmon (*Oncorhynchus tshawytscha*) migrated to their primary production areas between Marsing, Idaho, and Swan Falls, Idaho, approximately 300 river kilometers (rkm) upstream of the present spawning areas in Hells Canyon (Dauble et al. 2003). Current fall Chinook salmon spawning areas in the Snake River occur downstream of Hells Canyon Dam, which now is the upstream terminus for anadromous fish migration in the Snake River Basin. The historic spawning areas contained different water temperature regimes than the present spawning areas. Consequently, water temperatures during the egg incubation period (~December–May) may have been relatively warmer in the historic production areas than in the current spawning areas. This difference in temperature regimes may be the reason that fall Chinook salmon from current production areas in the Hells Canyon Reach arrive at the Lower Granite Dam section of the Snake River 1 to 4 weeks later than they did before development of the Hells Canyon Complex and the four lower Snake River projects operated by the U.S. Army Corps of Engineers (NMFS 2000a; Connor et al. 2001).

The shift toward later emergence and migration requires smolts to migrate through downstream reservoirs during mid- to late-summer when environmental conditions are unfavorable for survival (Connor et al. 2001). The differential survival among cohorts of wild Snake River subyearling juvenile Chinook can be traced back to emergence timing, with earlier emerging fish migrating earlier through Lower Granite Reservoir under conditions of higher flows and cooler water temperatures than later emerging fish (Connor 1999). Later migration puts juvenile migrants in reservoirs during periods when water temperatures approach Chinook salmon's thermal tolerance (NMFS 2000a). The delay also places late arriving fall Chinook in unsuitable reservoir environments, and may increase their susceptibility to predation.

p. 1.2

Recent research in the Hells Canyon Reach of the Snake River indicates that warm hyporheic water upwells into fall Chinook salmon spawning areas (Geist et al. 1999; Arntzen et al. 2001). The magnitude and duration of hyporheic water upwelling into these fall Chinook salmon spawning areas is inversely related to discharge from Hells Canyon Dam. During the October – December period when flows are held stable to allow fall Chinook salmon to spawn, the water temperature of the hyporheic zone is up to 2°C warmer than the river water, and hydraulic gradients suggest upwelling potential into the river channel. Under current operations by Idaho Power Company (IPC) and beginning in mid-October, the discharge from Hells Canyon Dam is lowered and daily fluctuations are minimized to benefit spawning fall Chinook salmon within the mainstem Snake River. As discharge decreases, the magnitude of hyporheic upwelling potential at these areas increases (Geist et al. 1999). The period of low, stable discharge from Hells Canyon Dam terminates at the end of the fall Chinook spawning period and the discharge pattern reverts to those of prior operations (i.e., large, variable discharge caused by power-peaking operations). By early December (i.e., early in the egg incubation period), the upwelling hyporheic water was 2°C warmer than the river water (Geist et al. 1999). It is likely that as incubation progresses into February and March, the difference in temperature between the hyporheic zone and the river becomes greater than 2°C. However, there are currently no empirical data quantifying the surface water–ground water interactions occurring during the fall Chinook salmon incubation and emergence periods within Hells Canyon, and thus no way to substantiate this hypothesis.

p. 2.6

L is the distance (cm) from the top of the piezometer screen to the riverbed surface. The VHG represents a potential for upwelling from the hyporheic zone (positive VHG) or downwelling into the hyporheic zone (negative VHG). Analyses of hydraulic gradients between the river and riverbed were primarily based on *dh* values. The *dh* values were used so that hydraulic gradients could be evaluated relative to the uncertainty error of the instruments (±1.4 cm), which does not vary over the range of depths for which they were used in this study. Differences in mean *dh* among sites and time period (spawning, early

p. 3.7

Each of the lower, middle, and upper segments of the study area included sites exhibiting both upwelling and downwelling potential. Sites within the lower segment had a mean *dh* ranging from -0.1 cm (±0.7 cm SD) to 1.6 cm (±0.4 cm SD) during the spawning period, from -0.9 cm (±0.6 cm SD) to 1.6 cm (±0.3 cm SD) during the early incubation period, and from -0.6 cm (±0.7 cm SD) to 3.2 cm (±0.9 cm SD) during the late incubation period (Figures 6 and 7). Within the middle segment, the range of mean *dh* among sites was much larger, ranging from -1.0 cm (±0.4 cm SD) to 4.7 cm (±0.5 cm SD) during the spawning period, from -1.5 cm (±0.7 cm SD) to 4.6 cm (±0.4 cm SD) during the early incubation period, and from -1.0 cm (±0.5 cm SD) to 4.7 cm (±0.8 cm SD) during the late incubation period (Figures 6 and 7). Sites within the upper segment also had a large range of mean *dh*, ranging from 0.3 cm (±0.7 cm SD) to 3.4 cm (±0.6 cm SD) during the spawning period, from 0.2 cm (±0.6 cm SD) to 3.7 cm (±0.6 cm SD) during the early incubation period, and from -0.3 cm (±1.6 cm SD) to 3.1 cm (±1.2 cm SD) during the late incubation period (Figures 6 and 7). Tests for differences in mean *dh* among all sites resulted in indications of significant differences for nearly all sites in all time periods (Tables 5 and 6). However, many of the differences in mean *dh* were less than 1.5 cm, which is approaching the pressure transducer uncertainty error of ±1.4 cm.

p. 3.11

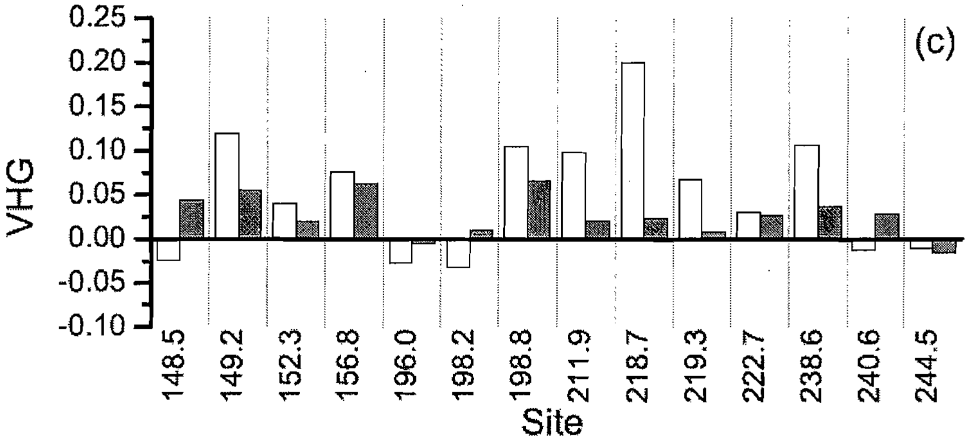


Figure 8. Mean vertical hydraulic gradient (VHG) between the river and shallow hyporheic zone (□), and between the river and deep hyporheic zone (■) during (a) the spawning period (20 October 2002 – 2 December 2002), (b) the incubation period with low, stable discharge (19 November 2002 – 7 January 2003), and (c) the incubation period with variable discharge (8 January – 2 March 2003). Positive values indicate upwelling potential while negative values indicate downwelling potential.

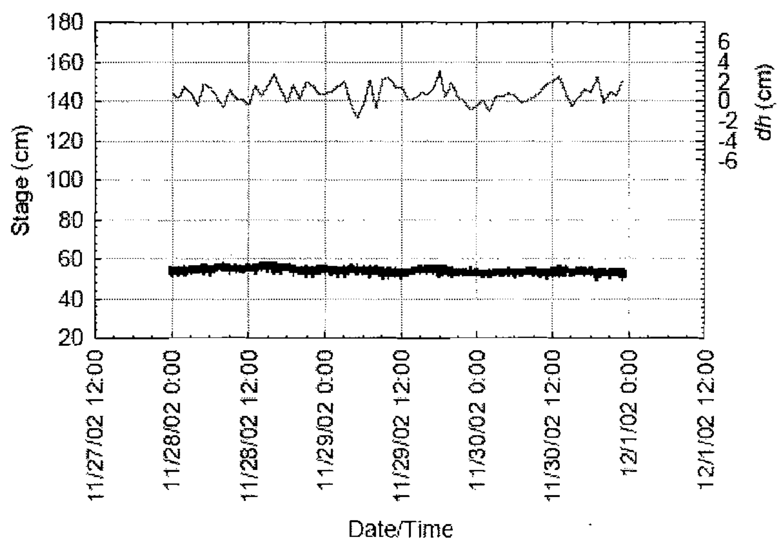
p. 3.37

Table 9. Summary of mean (± standard deviation) water temperature (°C) in the river (R), egg pocket (EP), shallow hyporheic zone (SH), and deep hyporheic zone (DH) at each site during the early spawning period (20 October 2002–18 November 2002), the mid-to-late spawning period and early incubation period (19 November–2 December 2002), the early incubation period with low, stable discharge (19 November 2002–7 January 2003), and the incubation period with variable discharge (8 January–2 March 2003). The overlapping time periods are provided for the separate analyses of fall Chinook salmon life stages (i.e., spawning and incubation).

3.37

Site	R	SH	DH
	Early spawning period		
L†			
148.5	10.0 (1.7)	10.3 (1.6)	10.6 (1.5)
149.2	9.9 (1.7)	10.2 (1.6)	10.9 (1.5)
152.3	10.0 (1.7)	10.9 (1.5)	11.4 (1.5)
156.8	10.1 (1.7)	10.4 (1.6)	10.8 (1.5)
M†			
196.0	12.5 (1.6)	12.5 (1.5)	12.6 (1.6)
198.2	12.6 (1.5)	12.6 (1.5)	13.0 (1.5)
198.8	12.5 (1.5)	12.7 (1.5)	12.9 (1.4)
211.9	12.5 (1.6)	13.0 (1.6)	13.5 (1.6)
218.7	12.7 (1.6)	13.2 (1.4)	13.4 (1.4)
219.3	12.6 (1.6)	13.0 (1.6)	13.0 (1.6)
222.7	12.8 (1.6)	13.3 (1.4)	13.4 (1.4)
U†			
238.6	12.8 (1.6)	13.1 (1.4)	13.6 (1.3)
240.6	12.8 (1.6)	13.1 (1.6)	13.3 (1.6)
244.5	12.8 (1.6)	12.8 (1.6)	13.0 (1.6)

p. A-14



Appendix Figure 14. Time-series summary of water temperature (top panel) and river stage (bottom panel) at site 244.5 during a period of low, stable river discharge (November 28 – 30, 2002). Average hourly water temperature is shown for the river (+), egg pocket (O), shallow hyporheic (●) and deep hyporheic (▲) zones. Average hourly stage (depth) is shown for the river (+), and shallow hyporheic zone (●). The difference between these two water depths (hyporheic minus river) is plotted on the Y-right axis as *dh* (—), with positive values indicating upwelling potential.

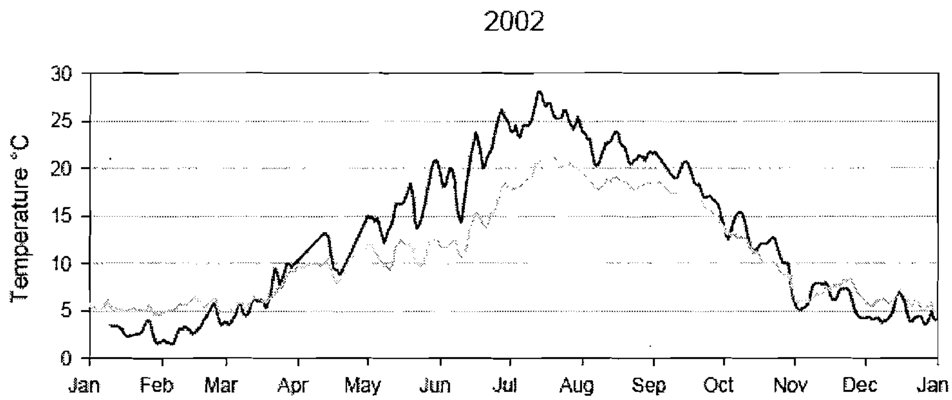


Figure 6.1-3. Measured and estimated historic (EHist) temperatures in degree Centigrade (°C) in the Snake River inflow to Brownlee Reservoir for medium (1995), high (1997) and low (2002) water years.

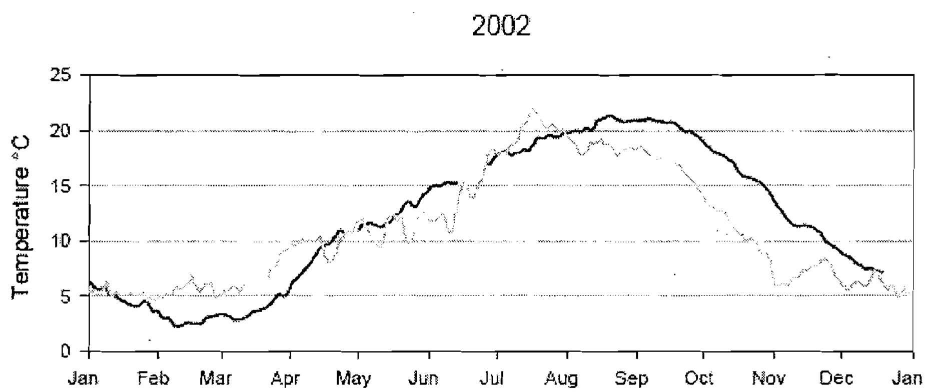


Figure 6.1-4. Measured Hells Canyon Complex (HCC) outflow temperatures in degree Centigrade (°C) and estimated historic (EHist) inflow temperatures in the Snake River for medium (1995), high (1997) and low (2002) water years.

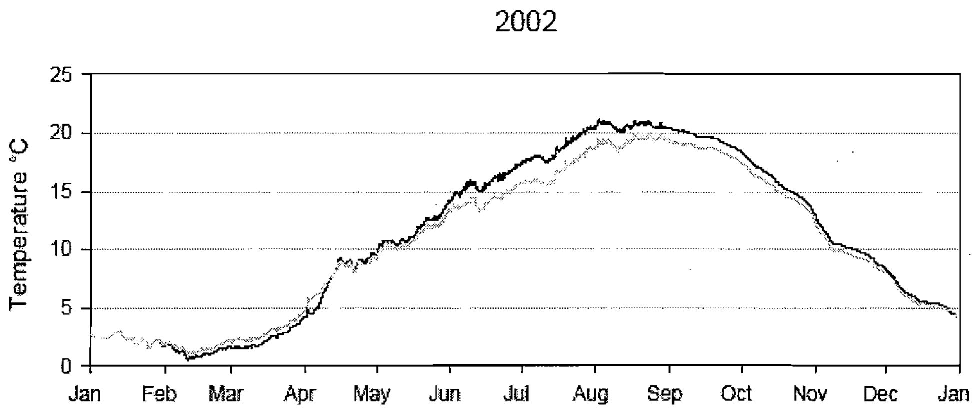


Figure 6.1-6. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for low water years (1992, 1994 and 2002).

p. 385.

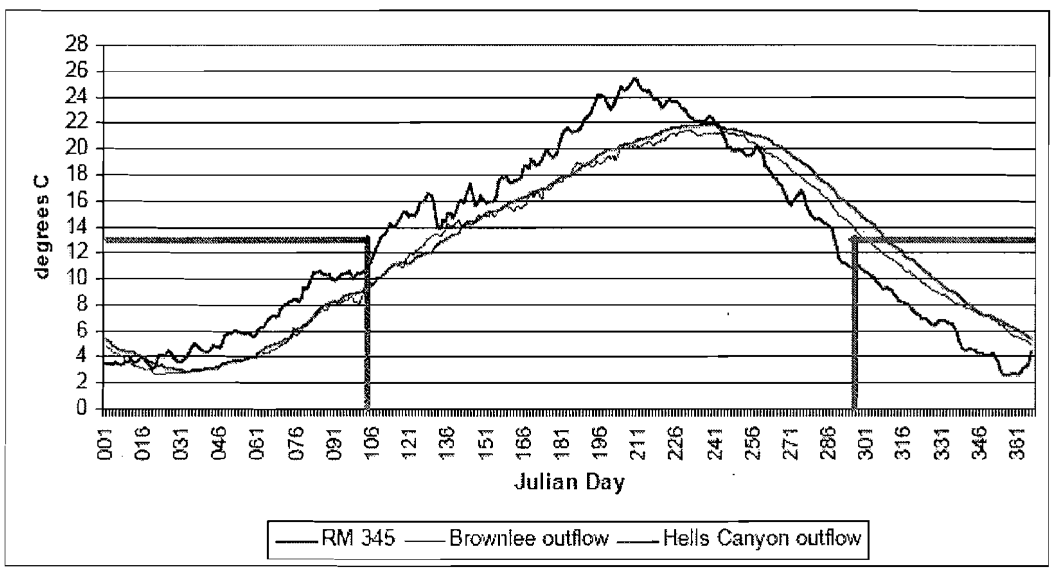


Figure 3.6.4 a. Post-construction daily mean water temperature data for the Snake River above and below the Hells Canyon Complex dams. (Salmonid spawning periods (boxes) for the Snake River below Hells Canyon Dam are displayed specific to fall chinook in this reach.)

Hanrahan et al. (2004)

p. 1.1

current spawning areas. This difference in temperature regimes may be the reason that fall Chinook salmon from current production areas in the Hells Canyon Reach arrive at the Lower Granite Dam section of the Snake River 1 to 4 weeks later than they did before development of the Hells Canyon Complex and the four lower Snake River projects operated by the U.S. Army Corps of Engineers (NMFS 2000a; Connor et al. 2001).

Geist, D. and A.Currie. 2006. Evaluation of Salmon Spawning below the Four Lowermost Columbia River Dams", 2004-2005 Annual Report, Project No. 199900301, 59 electronic pages,(BPA Report DOE/BP-00000652-32).

Examination of temperature data reveals several important patterns. Piezometer sites differ in the direction of vertical flow between surface and subsurface water. Bed temperatures in upwelling areas are more stable during salmon spawning and incubation than in downwelling areas. Bed temperatures in downwelling areas generally reflect river temperatures. Chum and fall Chinook salmon spawning is spatially segregated, with chum salmon in upwelling areas and fall Chinook salmon in downwelling areas. Although these general patterns remain similar among years, differences also exist that are dependent on interannual flow characteristics.

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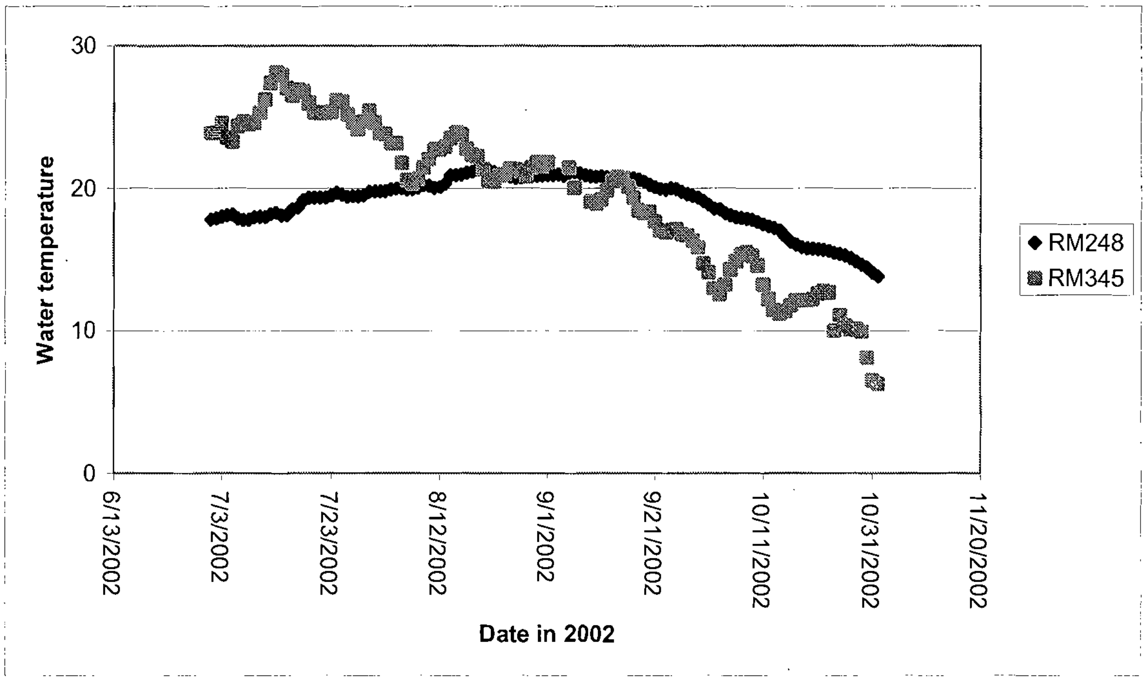
Plot below is from data sent to ODEQ by IPC for measured temperatures at RM248 and RM345 in 2002. Graph produced by McCullough (CRITFC) from IPC data.



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[Idaho Power Company (IPC). 2007. Section 401 water quality certification application. Hells Canyon Complex. FERC No. 1971. Submitted to Idaho Department of Environmental Quality and Oregon Department of Environmental Quality. January 31, 2007.]

The FERC project boundary for the HCC extends from just above Porter Island [River Mile (RM) 343], within Malheur County in the State of Oregon, about five miles northwest of Weiser, Idaho, to Hells Canyon Dam (RM 247.6) in Wallowa County, Oregon (Figure 1.1-1). (IPC 2007).

Measurements at Brownlee Dam showed unmixed conditions at the bridge (113%–138%), mixed conditions about four miles downstream of the dam (135%) (river mile 280.4)....

272.8 Oxbow Dam

(RM 345.6) and outflow from Hells Canyon Dam (RM 247.6).

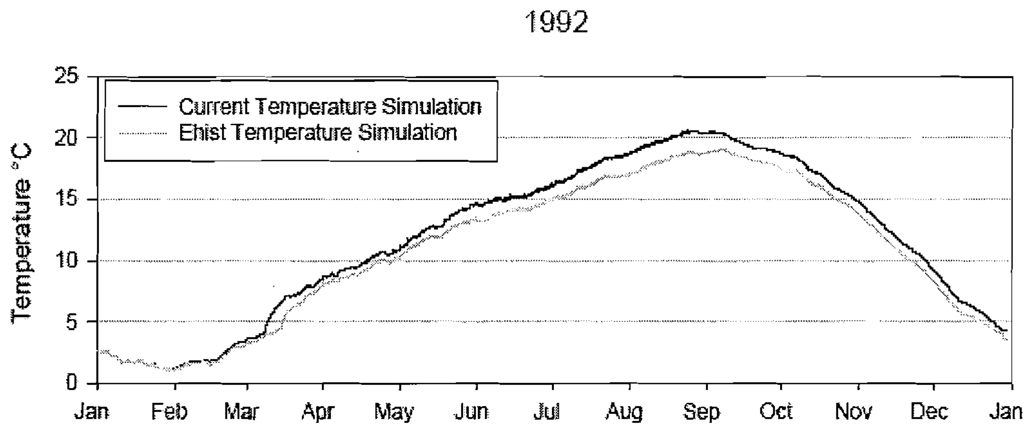

Figure 6.1-6. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for low water years (1992, 1994 and 2002).

<u>**Hydro Projects upstream of HCC**—data from</u>
www.nww.usace.army.mil/html/offices/pa/WRD-ID99.pdf
<u>http://www.nwcouncil.org/maps/power/Default.htm</u>

Lucky Peak (101mw Hydro)
Owner: Boise Proj. Board of Control, started 1988

Swan Falls (25mw Hydro)
Owner: <u>Idaho Power Co</u>., started **1901**. Acquired by IPC in 1916.
Reservoir holds 7,425 acre feet; at RM457

C.J. Strike (82mw Hydro)
Owner: <u>Idaho Power Co</u>., started **1952**
Reservoir holds 247,000 acre-feet; at RM494

Bliss (75mw Hydro)
Owner: <u>Idaho Power Co.</u>, started **1949**
Reservoir holds 8,415 acre-feet; at RM560

Lower Salmon Falls (60mw Hydro)
Owner: Idaho Power Co., started **1910**, rebuilt 1949.
Reservoir holds 10,900 acre-feet.

Upper Salmon Dam
Owner: Idaho Power Co.
Reservoir holds 600 acre-feet; at RM 580

Lower and Upper Malad Dams
Owner: Idaho Power Co., built **1911**
Upper Malad project on Malad River at RM 2.1; Lower Malad project on Snake River at RM 571.2

Twin Falls A & B (52mw Hydro)
Owner: Idaho Power Co., started **1935**; updated in 1995
Reservoir holds 955 acre-feet

Milner A (58mw Hydro)
Owner: Idaho Power Co., started 1992; in operation as an irrigation project since **1905**.
Reservoir holds 39,000 acre-feet.

American Falls (92mw Hydro)
Owner: Idaho Power Co. financed, operated by USBOR
Original dam was an earthen dam built in **1927**; reconstructed between 1976-1978.
Reservoir holds 1,671,300 acre-feet; at RM 715.

Thousand Springs Dam
Owner: Idaho Power Co.; built **1912**, updated 1921.
8.8 mw;

Clear Lake Power Plant
Owner: Idaho Power Co.; build **1937**
at RM 593

Shoshone Falls Dam
Owner: Idaho Power Co.; build **1907**, rebuilt 1921.
Reservoir holds 1,500 acre feet; at RM 615

Palisades (118mw Hydro)
Owner: U.S. Bureau of Reclamation, started **1957**

Minidoka (27mw Hydro)
Owner: U.S. Bureau of Reclamation, started **1906**
Capacity at Elev: 4245.0 ft, Usable storage of 210,000 acre-feet
at RM675.

- --------

Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin

M. L. KEEFER*†, C. A. PEERY*, M. A. JEPSON* AND L. C. STUEHRENBERG‡

Journal of Fish Biology (2004) **65**, 1126–1141

Oncorhynchus gorbuscha (Walbaum) (Smoker *et al.*, 1998) salmon. Strategies for optimal adult arrival range from very early migration and long freshwater residence (*e.g.* some steelhead and Atlantic salmon stocks) to rapid migration by mature fishes just prior to spawning [*e.g.* some Columbia River autumn (fall) Chinook salmon]. With either strategy, arrival at the most suitable time can lead to reproductive advantages for individual fish, such as selection of prime spawning sites and safe holding positions, and improved overall population fitness (Hawkins & Smith, 1986; Smoker *et al.*, 1998). Alternatively, fishes entering the river relatively late within each run face reduced mating opportunities if they reach the spawning grounds after most spawning activity has occurred. These fishes may swim more rapidly, irrespective of discharge or temperature to reach spawning grounds before the window of opportunity for spawning closes. The observed seasonal increase in spring–summer Chinook salmon migration rates may incorporate a variety of these mechanisms, though the contribution of each remains unknown.

consequences for overall survival. Longer adult exposure to elevated temperatures may result in higher prespawn mortality (Gilhousen, 1990; Dauble & Mueller, 2000; C.B. Schreck, J.C. Snelling, R.E. Ewing, C.S. Bradford, L.E. Davis & C.H. Slater, pers. comm.) or reduced gonadal development or egg viability (Kinnison *et al.*, 2001). Further research on the relationships between river discharge and temperature, migration rates, spawning success and juvenile recruitment are recommended for managers interested in protection and enhancement of extant stocks.

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Late-season mortality during migration of radio-tagged adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River

George P. Naughton, Christopher C. Caudill, Matthew L. Keefer, Theodore C. Bjornn, Lowell C. Stuehrenberg, and Christopher A. Peery

Abstract: We radio-tagged 577 adult sockeye salmon (*Oncorhynchus nerka*) returning to the Columbia River in 1997 to determine how migration behaviors were related to migration success in an altered river system. The probability of successful migration declined dramatically for late-entry individuals, concomitant with declines in discharge and the onset of stressful temperatures. Long dam passage times were not related to unsuccessful migration at most dams. However, when migration histories were analyzed across multiple dams or reservoirs, relatively slow migration was significantly associated with unsuccessful migration, suggesting potential cumulative effects. Median passage times at dams were rapid (7.9–33.4 h), although 0.2%–8% of salmon took more than 5 days to pass. Reservoir passage was also rapid, averaging 36.8–61.3 km·day^{-1}, and appeared to compensate for slowed migration at dams. Rates observed in the unimpounded Hanford Reach suggest that total predam migration rates may have been similar to current rates. Overall, our results suggest that cumulative effects may be more important than negative effects of passage at single dams and that hydrosystem alteration of temperature regimes in the migration corridor may have an important indirect negative impact on adults.

Can. J. Fish. Aquat. Sci. 62: 30–47 (2005)

Nonetheless, temperature was probably the primary factor affecting migration success. Elevated water temperatures during upstream migration have been linked to higher in-river and prespawning mortality of sockeye salmon in the Columbia Basin (Major and Mighell 1967) and the Fraser River (Gilhousen 1990; Macdonald et al. 2000; Cooke et al. 2004). Adult exposure to elevated temperatures can increase susceptibility to disease and compromise reproductive performance (Coutant 1999; Torgersen et al. 1999) through increased metabolic demands (Rand and Hinch 1998), reduced allocation to gonadal development (Kinnison et al. 2001), and reduced egg viability (Berman and Quinn 1991). Extended exposure of adult salmonids to water temperatures >18 °C may increase the risk of prespawning mortality (mortality after adults have reached spawning tributaries; Becker and Fujihara 1978; Gilhousen 1990), and temperatures above 24 °C are lethal (Servizi and Jensen 1977). Cooke et al. (2004) identified several mechanisms that may have contributed to the dramatic in-river and prespawn mortality observed in late-run sockeye salmon in the Fraser River since 1995. While underlying causes of mortality are still unclear in the Fraser River, it is likely that temperature plays a direct or indirect role because the high mortality has been observed in a portion of the run entering the river more than 6 weeks earlier in the season than the historical pattern, shifting migration to a period of warmer water temperatures in August (Cooke et al. 2004). In our study, the precipitous drop in migration success occurred for sockeye salmon tagged after the second week of July as temperatures at Bonneville Dam and elsewhere in the drainage exceeded 20 °C.

the late period did not die immediately after release. Finally, we estimated survival for sockeye salmon migrating during these two periods using dam count data from Bonneville and Rock Island dams and assuming a 16-day passage time between these dams (the mean migration time observed for sockeye salmon tagged on 4–16 July). Although these estimates have several potential sources of error, a large decline in survival was also observed in the dam count sample, with estimated migration success dropping from 94.2% to 56.3% later in the summer. Taken together, ancillary evidence sug-

Several mechanisms may have contributed to the observed relationships among migration success, speed, and season. First, the relationship between migration success and speed could be direct, where slowed migration caused by dams resulted in the expenditure of energy that slowed migration at upstream projects and subsequently lowered the probability of successful migration. Alternatively, slow migration may have resulted from poor initial physiological condition leading to slowed migration, increased thermal exposure, and subsequent low probability of migration success. These two

Notably, the seasonal pattern of mortality may have been related to both factors. It is plausible that late-entry fish were in relatively poor initial physiological state, perhaps having delayed entry to continue ocean feeding, and this subsequently led to poor initial condition, slow migration rates, increased thermal exposure, and low migration success. Clearly, understanding the relationship between initial condition and migration success is important in a management context because the relative importance of each mechanism will determine the effectiveness of management actions aimed at improving passage conditions at dams — efforts to improve passage at dams will provide little benefit if migration success is primarily related to fish condition at river entry.

Regardless of mechanism, the observed pattern of seasonal mortality suggests the potential for current selection on run timing. The upstream migration of anadromous salmonids is an energetically demanding part of the life cycle and its initiation is largely governed by the interactions of water

temperature, flow regime, and other factors that influence maturation (Gilhousen 1990; Hodgson and Quinn 2002). Substantial variation exists in the timing of spawning migrations of North American sockeye salmon populations and is thought to relate to temporal variation in both migration conditions for adults and spawning and rearing conditions in tributaries (Tagaki and Smith 1973; Merritt and Roberson 1986; Hodgson and Quinn 2002). For example, Columbia River and interior British Columbia stocks of sockeye salmon tend to enter fresh water before peak summer temperatures and hold in spawning tributaries for 1 month or more before fall spawning whereas coastal stocks migrate after peak temperatures just prior to spawning (Gilhousen 1990; Hodgson and Quinn 2002). Quinn and colleagues (Quinn and Adams 1996; Quinn et al. 1997; Hodgson and Quinn 2002) have used dam counts and historical records to examine the relationships between run timing and environmental conditions. They found that sockeye salmon passed Bonneville Dam progressively earlier over the period 1949–1993, concomitant with a progressive increase in the mean temperatures that migrating adults experienced in the lower Columbia River (Quinn and Adams 1996). Patterns of individual mortality during 1997 in relation to run timing and temperature were consistent with selection for earlier run timing within these populations, as hypothesized by Quinn and Adams (1996).

If such selection is real and leads to evolution of earlier run timing, we speculate that the energetic costs of migration will increase in coming decades. Recent regional climate projections predict increasingly early winter snowmelt, longer dry periods during summer, and later onset of fall conditions (Parson et al. 2001). If true, these conditions would lead to continued selection for early run timing in Columbia River sockeye and other spring-run salmonids. The energetic costs of migration will likely increase because fish will either hold without feeding in spawning tributaries for longer periods or experience higher temperatures during migration if populations do not respond to selection as rapidly as conditions change or both. This increase in energetic cost could lead to greater in-river or prespawn mortality, particularly in warm years and for stocks migrating long distances.

Technical Report – 2006-3

Water Temperatures in Adult Fishways at Mainstem Dams on the Snake and Columbia Rivers: Phase 2 — Biological Effects.

by

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and

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Climate projections for the interior Pacific Northwest suggest higher summer temperatures, less winter snowpack, and consequently, longer, warmer summers with lower stream flows (e.g., Mote et al. 2005, Stewart et al. 2005). These projections suggest that management of the hydrosystem thermal regime will become increasingly important to the recovery of Snake River summer and fall Chinook salmon and steelhead, particularly late spring-early summer runs (e.g., summer Chinook) and early fall run groups that currently experience the highest temperatures (e.g. Snake River A-run steelhead). If current climate predictions hold, modifications to fishways to ameliorate ladder temperature differences could be an important component to the management of the Snake River Hydrosystem thermal regime.

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by

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Technical Report 02-1

WATER TEMPERATURES AND PASSAGE OF ADULT SALMON AND STEELHEAD IN THE LOWER SNAKE RIVER

conservative test results. Travel times between Ice Harbor and Lower Granite dams for chinook salmon trended upward when temperatures at Lower Granite Dam were higher, but travel times between the two projects for steelhead were not significantly related to prevailing water temperatures. In short, we saw evidence that some chinook salmon and steelhead would delay entry into the Snake River during warm water conditions and some chinook salmon, but not steelhead, traveled slower through the lower Snake River when water temperatures were high. In contrast to radio-telemetry data, there was a relatively good correlation between when the first quartile of salmon and steelhead were counted at Ice Harbor and Lower Granite dams and water temperatures. Fish passed the dams later on years when average summer-time water temperatures were high, additional evidence that some salmon and steelhead will delay their upstream migration to avoid warm water conditions.

The second behavioral response to water temperatures by salmon and steelhead we saw was a delay by some fish in passing dams when temperatures were unfavorable, when temperatures exceeded 20°C and when there was a noticeable difference in temperatures between the tailrace and forebay surface, creating a sharp delineation where these two sources of water met in the fishways. Ironically, this condition was

Hydrosystem, Dam, and Reservoir Passage Rates of Adult Chinook Salmon and Steelhead in the Columbia and Snake Rivers

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Transactions of the American Fisheries Society 133:1413–1439, 2004

Fall Chinook salmon migrations were characterized by low discharge, especially in 2001. Migration rates from Bonneville Dam to McNary Dam decreased significantly in 2001, but not significantly in 2000, as discharge increased (Table A.1). Fall Chinook migrated significantly faster as temperatures decreased in 2000. The relationship was parabolic in 2001; passage rates were lowest when water temperatures were warmest and, again, late in the migration when temperatures were low.

Fallback.—For all years combined, 19% of spring, 8% of summer, and 3% of fall Chinook salmon fell back over and reascended a dam at least once before passing McNary Dam (Table 4).

High water temperature during upstream migration has been linked to higher prespawning mortality for spring Chinook salmon (Schreck et al. 1994), summer and fall Chinook salmon (Dauble and Mueller 2000), and sockeye salmon (Major and Mighell 1967) within the Columbia River basin; sockeye salmon in the Fraser River, British Columbia (Gilhousen 1990); and for steelhead in several systems (Baigun et al. 2000). Maximum river temperatures in all years of this study were within the range that could block adult migration (McCullough et al. 2001). Exposure to elevated water temperatures can increase susceptibility to disease and compromise reproductive performance through increased metabolic demands, reduced allocation to gonadal development, and reduced egg viability (Berman and Quinn 1991; Rand and Hinch 1998; Torgersen et al. 1999; Hinch and Rand 2000; Kinnison et al. 2001). In the Columbia basin, use of thermal refugia may ameliorate some costs of high main-stem temperatures, particularly for steelhead that pass through the lower river 6–10 months before spawning. However, obligate migrants, such as summer and fall Chinook, may be compromised by temperature-related delays and exposure to sublethal temperatures that could elevate metabolic costs, alter energy allocation, or delay arrival at spawning grounds.

dams. High water temperatures slow some migrants, especially steelhead and fall Chinook salmon that pass through the lower river between July and September. Studies that more fully examine relationships between spawning success, migration delays, fallback, temporary straying, and sublethal temperature exposure are needed to evaluate the reproductive costs and population-level effects of migration through the hydrosystem for adult fish. Large-scale, multiyear telemetry studies us-

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FINAL REPORT

STOCK ASSESSMENT OF COLUMBIA RIVER
ANADROMOUS SALMONIDS

VOLUME I: CHINOOK, COHO, CHUM AND SOCKEYE SALMON STOCK SUMMARIES

by

Philip Howell
Kim Jones
Dennis Scarnecchia
Oregon Department of Fish and Wildlife

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SNAKE RIVER FALL CHINOOK

Sex ratio

Richards (1961) obtained sex ratio information throughout the spawning period and found it to be 0.5:1 male to female. He also found that the ratio varied considerably among individual surveys.

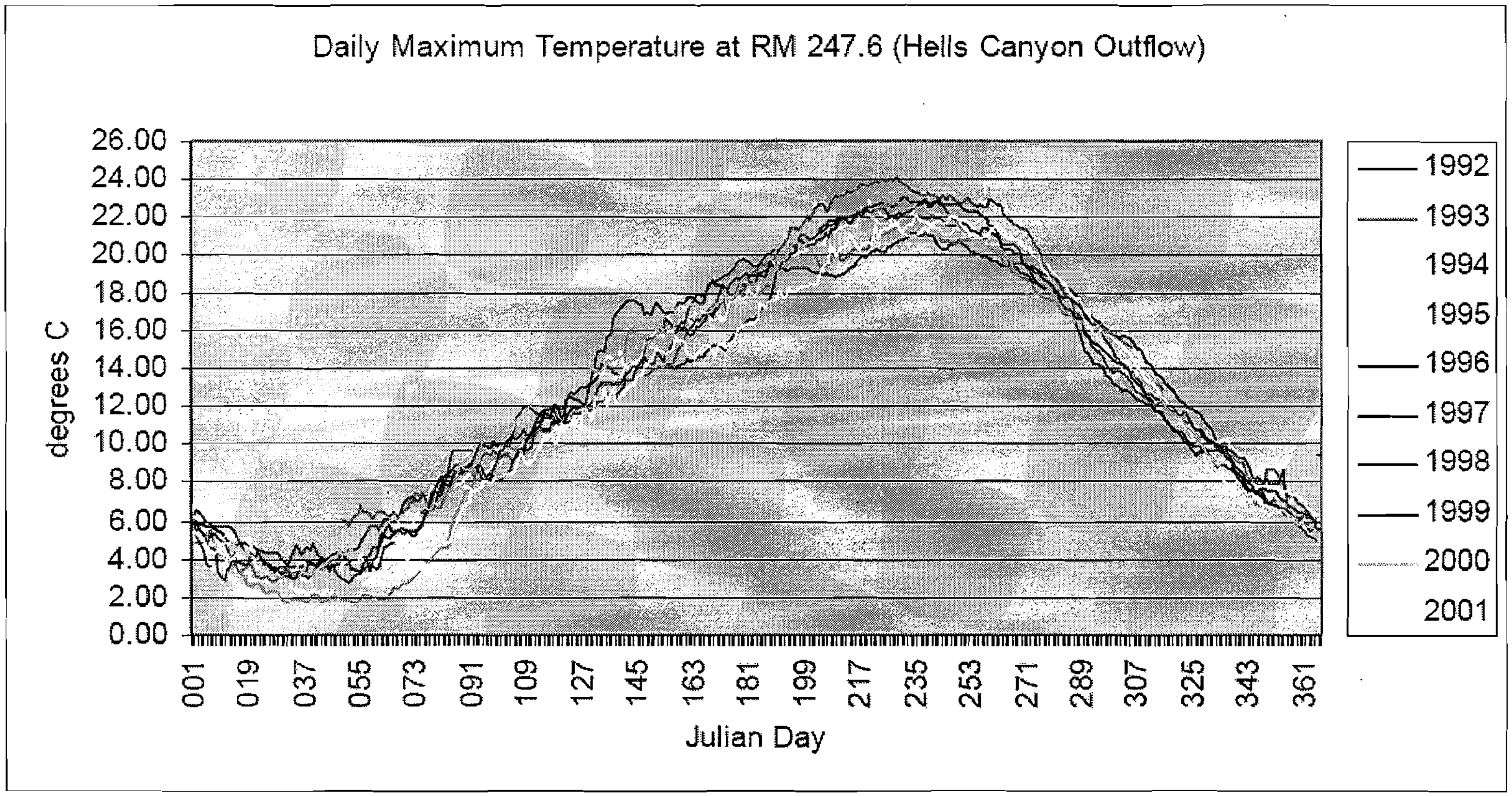
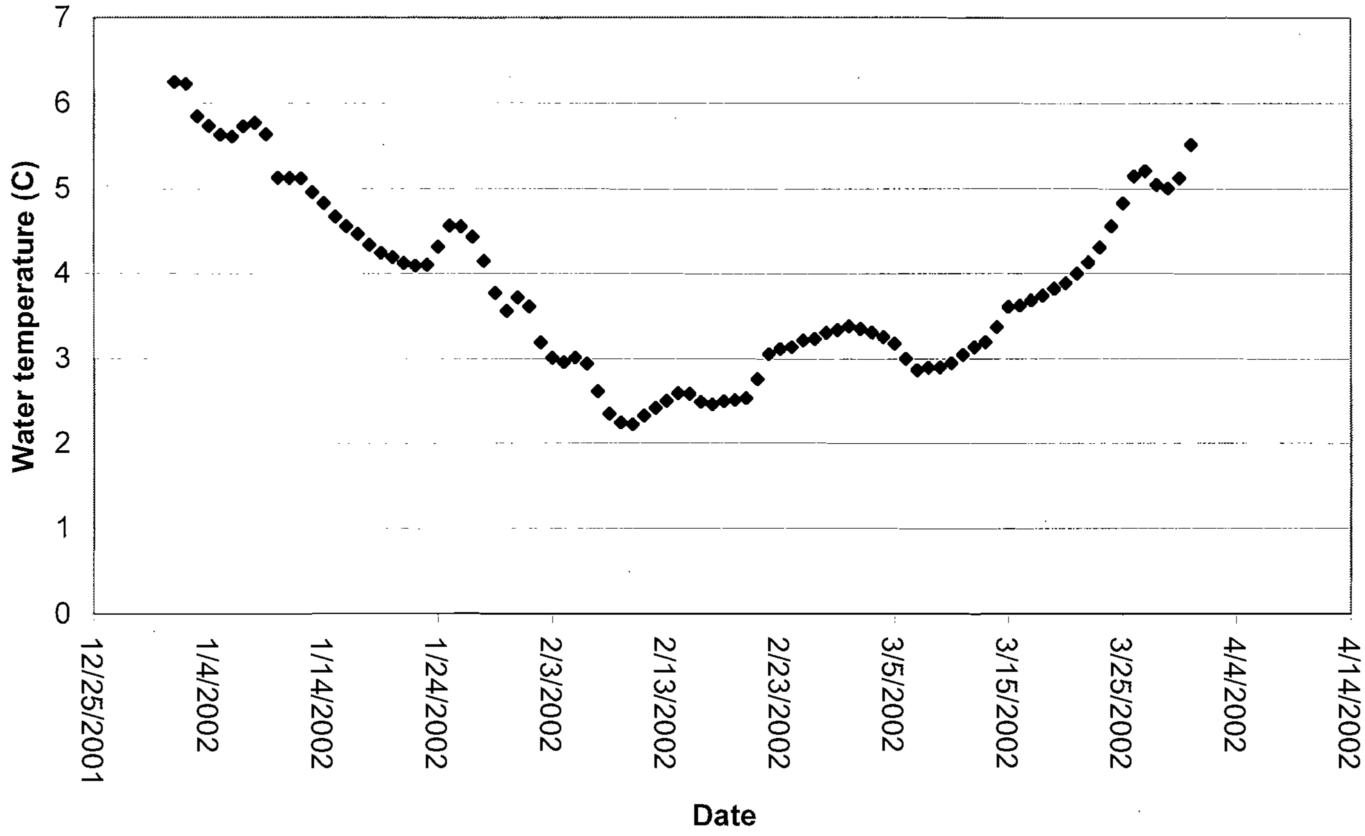


Figure 3.6.2 e. Water temperatures for the Downstream Snake River segment (RM 247 to 188) of the Snake River - Hells Canyon TMDL reach near Hells Canyon Dam.

Temperatures at RM 247.6 on the Snake River below HCD during the winter-spring of 2002. Based on data provided by IPC to ODEQ. Graph by McCullough (CRITFC, 2007).



**Lower Snake River Water Quality
And Post-Drawdown Temperature
And Biological Productivity Modeling Study**

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Walla Walla District
US Army Corps of Engineers
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US Army Corps of Engineers
May 1999

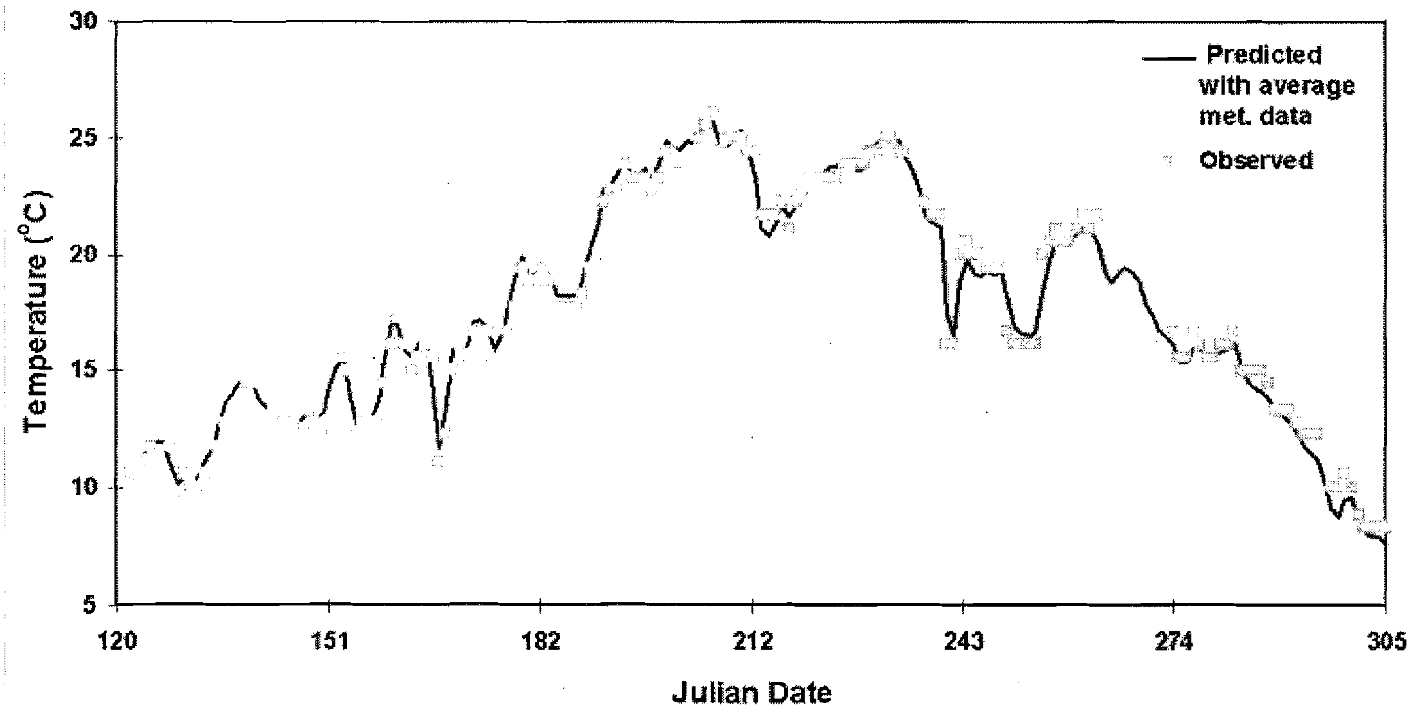

Figure 5.4-13. 1956 water temperatures at Central Ferry

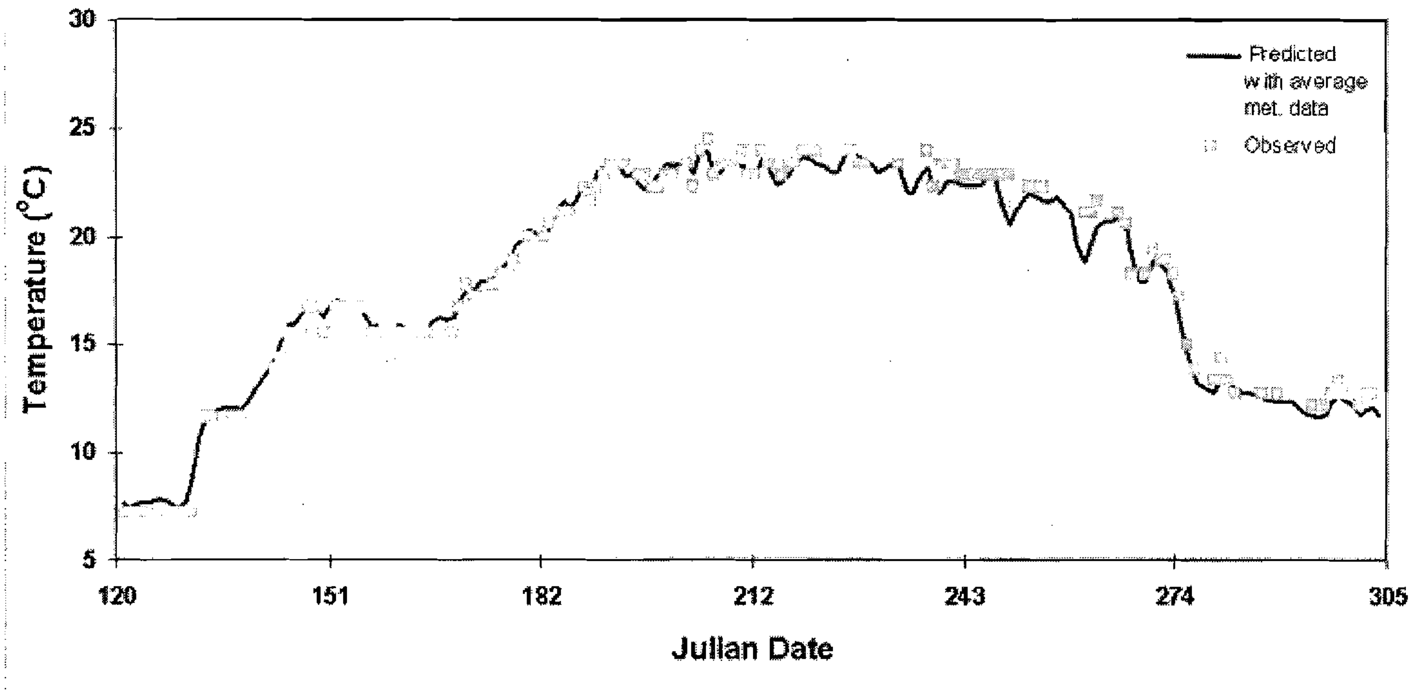

Figure 5.4-15. 1957 water temperatures at Central Ferry

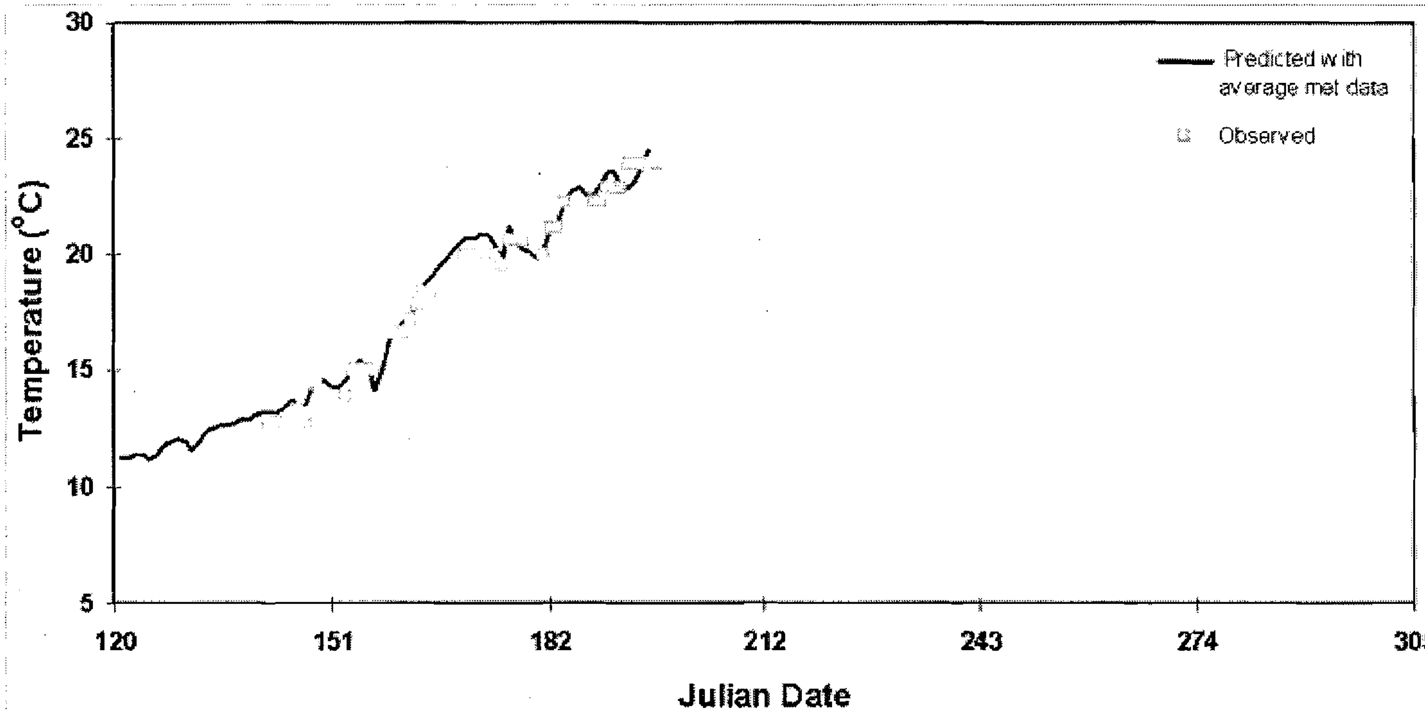

Figure 5.4-17. 1958 water temperatures at Central Ferry

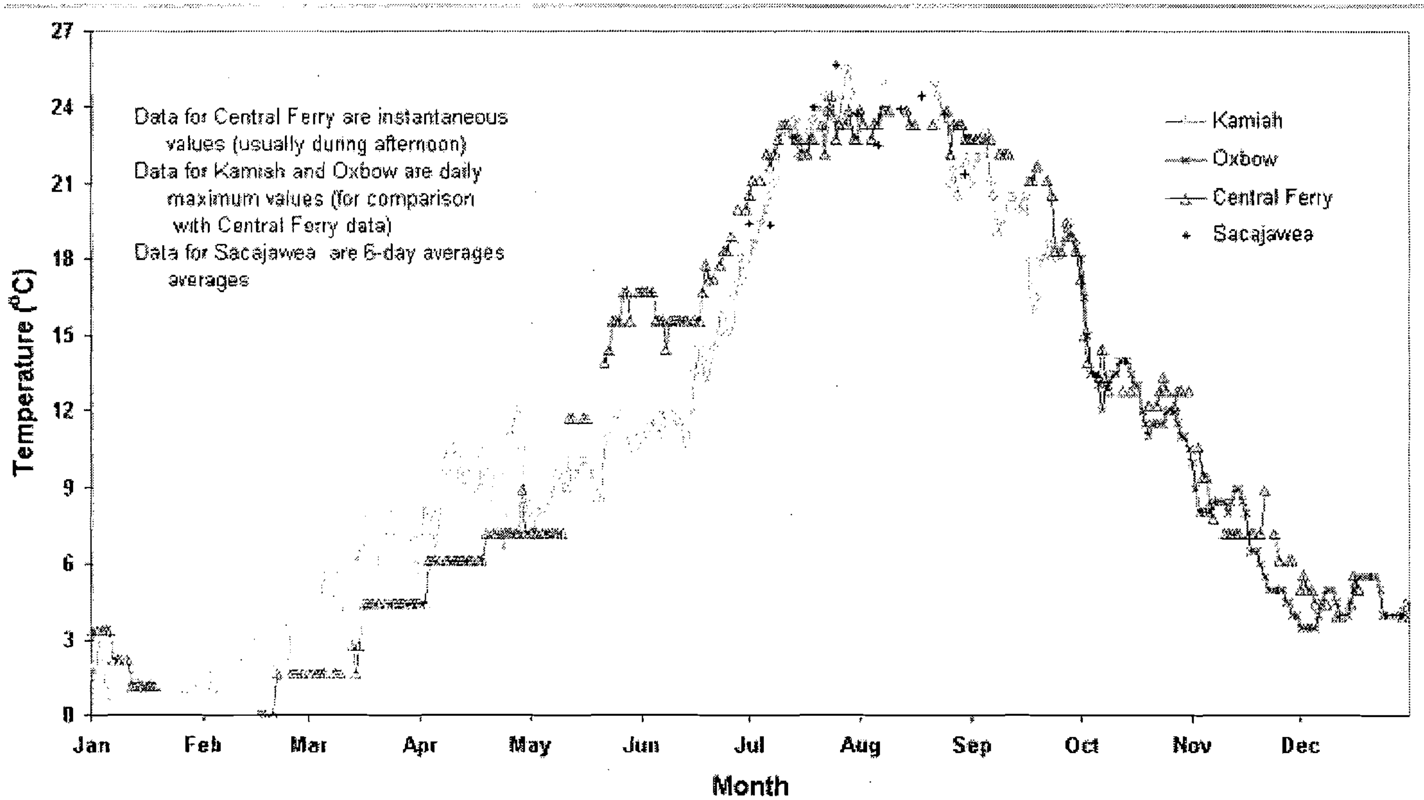

Figure 5.4-8. 1957 Snake River and Clearwater River water temperatures

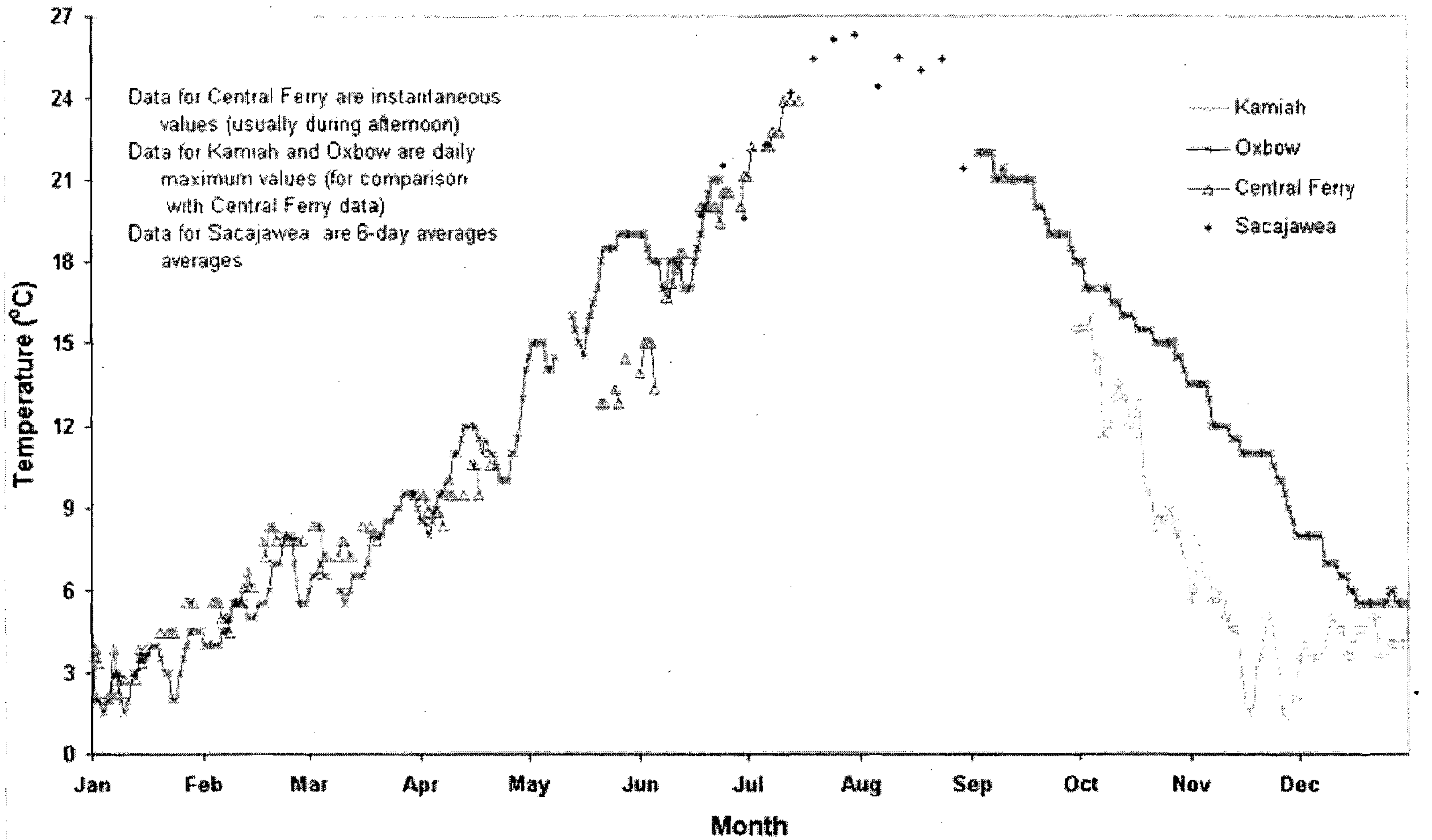

Figure 5.4-9. 1958 Snake River and Clearwater River water temperatures

Table 5.4-6
Listing of Stations with Observed Temperature Data Prior to Mid-1960's

Location	River Mile	Period of Record	Data Frequency	Data Source
Snake River at Sacajawea	(near mouth)	June through September for each year, 1955 through 1958	6-day averages	Graph of data provided by the Corps
Snake River at Central Ferry	83.2	October 1955 to July 1958	Instantaneous daily measurements	Copies of original USS data sheets provided by the Corps
Snake River near Clarkston (11343500)	132.9	October 1959 to September 1964	Daily min/max	Hydrosphere, Inc., CD (data originally from USGS)
Snake River near Anatone (13334300)	167.2	October 1959 to present	Daily min/max (prior to 1978)	Hydrosphere, Inc., CD (data originally from USGS)
Snake River at Oxbow (13290200)	269.6	October 1957 to September 1973	Daily min/max	Hydrosphere, Inc., CD (data originally from USGS)

UNITED STATES OF AMERICA

FEDERAL ENERGY REGULATORY COMMISSION

Idaho Power Company	)	Project No. 1971-079 Hells Canyon Hydroelectric Project
Application for New Major License Hells Canyon Project On the Snake River, Idaho	)	REVIEW OF THE JULY 2007 WHITE PAPER SUBMITTED BY IDAHO POWER COMPANY WRITTEN BY GROVES, ET AL BY DALE A. MCCULLOUGH

CERTIFICATE OF SERVICE

I hereby certify that I have this day complied with the Federal Energy Regulatory Commission's rules regarding service by serving this filing upon each person designated on the official service list compiled by the Secretary in this proceeding.

Submitted this 30th day of August, 2007.

Ryan Sudbury
Attorney for the Nez Perce Tribe